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Operator-Interactive Signature Formation for Acoustic Undersea Surveillance Systems

[Unclassified Title]

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Advanced Projects Group
Acoustics Division

October 1977

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(C) An experiment designed to permit organization of acoustic signals detected in undersea surveillance systems by combining the observational power of a human operator with the storage and computational power of a computer is described.

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OPERATOR-INTERACTIVE SIGNATURE FORMATION FOR ACOUSTIC UNDERSEA SURVEILLANCE SYSTEMS
[Unclassified Title]

(C) ABSTRACT

This report describes an exploratory development for systematic organization of acoustic signals detected by multi-beam Undersea Surveillance Systems into the acoustic signature of ships. The function described is a subset of an NRL concept for an integrated, multi-platform, undersea surveillance system known as ASP - the Advanced Surveillance Processor. The concept, ~~is~~ termed "operator-interactive signature formation", ~~and~~ combines the observational power of a human operator with the storage and computational power of the computer. The interaction consists of a human operator proposing candidate harmonic series by indicating one or more harmonics of that series with ~~by means of~~ a cursor or hand-held pointer on an acoustic display on the face of a cathode ray tube. (Signal detection and parameter estimation are accomplished by existing algorithms prior to display.) Subjective interpretations by the operator are not permitted. Ambiguities in the signature formation process are resolved by execution ~~of~~ appropriate signal processing algorithms. Organization of the detected signals is a four-stage process beginning with identification of non-ship interfering signals, proceeding through harmonic set formation to combination of harmonic sets into signatures, and finally to highly automated "steady state" maintenance. The project is currently at the point where signature formation logic has been developed to the third level of complexity, approximately 70 application programs have been identified and initially specified, and display programming for a particular (dark-trace, storage) display has been completed.

a CRT screen,

begins with identifying

(C) BACKGROUND

This development emerged from a FY'75 study of technology gaps in the area of line relate and clue extraction for the 1980's Undersea Surveillance System, and was sponsored by the Naval Electronic Systems Command (Code 320). The results of the study indicated that major deficiencies exist in our knowledge of target acoustic characteristics, in the methods and procedures used in organizing and interpreting detected signals, in the applicability of various exploratory developments in signal processing, and in the type and quantity of display systems required for effective ocean surveillance. The conclusion of the study, the details of

Note: Manuscript submitted September 27, 1977.

which are contained in reference (1), was that the principal obstacle in the path of automating undersea surveillance was the problem of organizing the detected signals into meaningful groupings prior to classification. A three phase development was planned. Phase 1, Concept Definition and Logic Development, is documented by this report. Phase 2, implementation, involves assembling the required hardware/software and coding the application programs. Phase 3, Testing and Evaluation, involves exercising the system with non-inbred acoustic data.

(C) INTRODUCTION

(C) A study of the state-of-the-art of acoustic signature formation in multi-beam undersea surveillance systems, conducted in FY'75, revealed several serious technology gaps.[1]

1. As a practical matter, it is seldom, if ever, possible to distinguish, on the basis of acoustics alone, between "threat" and "threat like" detections in general surveillance.

2. Although ambiguities in the signature formation process were known to occur frequently, the acoustic information necessary to resolve these ambiguities was not known.

3. The sequence of procedures in signature formation, even for manual systems, was incomplete and inadequate.

4. Existing man-display interfaces were inadequate and resulted in incomplete and erroneous data being extracted from the display.

5. Measures of operator performance and decision criteria were largely undefined. Critical decisions were frequently made on the basis of operator "experience" or "intuition".

   (C) The study considered in detail the four generic approaches to signature formation, namely: manual, totally automatic, threat filtering, and operator-machine in combination. The manual, totally automatic, and threat filtering approaches were rejected for the following reasons:

<u>Manual</u> - the complexity of the problem is such that the human's solution is necessarily incomplete. Critical decisions are made on the basis of subjective or intuitive judgments.

<u>Totally Automatic</u> - This approach has consistently resulted in generation of fictitious signatures from fragments of real signatures, and in dismissal of real signatures through false association with other signatures.

<u>Threat Filtering</u> - This approach is not a signature formation technique but merely a discrete frequency detection technique. It was considered as an alternative to the other approaches. In practice, threat filtering results in high false alarm and false dismissal rates, since the acoustic characteristics stated for the threat are not unique to that class, and measures of dispersion are not known.

A more complete discussion of these techniques and their performance is given in reference (2).

(C) If undersea surveillance systems are to perform in the general surveillance mode, it is necessary to reduce the false threat declaration rate drastically, while retaining a false dismissal rate near zero. The study concluded this could be done if the problem is addressed systematically and objectively.

(C) The approach selected as having the best chance of success was a man-machine combination known as "Operator-Interactive Sector Scan". In this approach, the observational and pattern recognition powers of the human operator are utilized early in the signature formation process, not, as in past efforts, where his role was to correct the many errors made by the computer. The man suggests a candidate solution by interaction with the displayed acoustic spectrum. The computer verifies and expands the solution where appropriate, rejects it as incorrect, or in the case of ambiguity, executes the pertinent ambiguity-resolving signal processing algorithm. Subjective interpretations by the man, such as source evaluations, are not permitted.

Ambiguities, unresolvable by algorithm, are displayed for human interpretation only when the interaction required of the operator can be predefined.

(C) The signature formation process (Fig. 1) proceeds through four stages. First, non-ship "clutter" - station artifacts, projectors, "commas", etc., are identified. Next, candidate independent harmonic series on a particular beam are indicated by the operator. The algorithm makes the required calculations and verifies and expands the solution. The third stage attempts to associate independent harmonic sets to form ships' signatures. Finally, when "steady-state" is reached, the solution is maintained with a high degree of automation, operator interaction being required only when a significant change occurs which presents an ambiguity unresolvable by the steady state algorithm.

(C) The "Sector Scan" above refers to the concept for implementation wherein each operator at an upgraded SOSUS NAVFAC monitors a particular azimuthal sector. Since most beams at most NAVFACS seldom, if ever, hold contact on a genuine threat target, expanded spatial searchlighting is a legitimate technique which permits the number of displays necessary to be monitored simultaneously to be minimized. (Ref. 3).

(C) <u>System Overview</u>

(U) The equipment configuration for the experiment shown in Fig. 2 represents a mix of individual elements adequate for the experiment, but chosen mainly because of no-cost availability or minimum cost to acquire. Particularly in the display area, a refresh CRT with track ball controlled cursors would have been preferrable to the DICOMED-SAC (dark trace storage CRT and sonic pen) arrangement. A detailed discussion of DICOMED programming is given in Appendix A. A discussion of an optimum display is given in Appendix B.

(U) Top level signature formation logic is given in Fig. 3. The following illustrates the procedures used.

(C) The operator is required to monitor continually the SOSUS baseband (10-150 hz) in his assigned sector. For purposes of the experiment, the sector is defined as seven, fixed, contiguous beams. The real-world test data consists of seven magnetic tape recorded channels of 4 to 6 hours duration spectrum analyzed data at baseband (0.1 hz), vernier (.03 hz), and supervernier

(.010 hz) resolutions with accompanying parameter estimation.

(C) The sequence begins with a forty minute duration broadband display (150 hz) of the left-most beam, i.e., channel 1 of the magnetic tape recording. The operator attempts to recognize rather well known non-ship interference in one or more of three general classes - station equipment artifacts, man-made ocean noise, or sea noise. The suspected presence of any of these is indicated by pointing to one or more components with the interactive device, in this case a sonic-pen. A non-ship clutter recognition algorithm, if it confirms the operator's judgment, seeks to identify the interfering signals on the other seven beams as well. (Non-ship clutter is frequently visible on many beams simultaneously). A feature of this stage is that the operator, disagreeing with the algorithm can call for higher resolution displays, and as a result, present additional information to the algorithm. He cannot, however, override the algorithm's classification and force a classification of "clutter". If the algorithm does not call a signal "clutter", it is carried as a ship's signature. The concept here is that this type of interference is so well defined that algorithm performance is expected to be at least as good as the best human. Since it is possible that more than one type of clutter exists on this beam, the operator remains in stage one until he indicates interactively he is ready to proceed to beam two and ultimately, to stage two. All signals identified as non-ship clutter are tagged in the parameter estimation tables for each resolution.

(C) Stage two, harmonic set formation, is the most difficult to accomplish. The operator selects the most visually striking signature on the display, usually one rich in harmonics and signal-to-noise ratio. He indicates interactively some number of harmonics of the series. For multiple line signatures, this means a minimum of two adjacent harmonics. The algorithm calculates a trial fundamental, finds other harmonics of the set in the parameter estimation tables, and determines, on the basis of harmonics present and strength of harmonics, if this or another beam is the main lobe detection. The results are presented to the operator for verification. He is permitted to disagree on the basis of an observation of inconsistency in the solution. For example, a minor dynamic, not resolved by the parameter estimation algorithm, may be clearly visible in some, but not other, candidate harmonics. If the operator concurs, the parameter estimation table is tagged appropriately. Next, a threat potential algorithm is executed. This is merely a conservative "clearly non-threat" vs "possible threat" distinguishing algorithm. An attempt is made to localize "Possible threats" by both data processing (maneuvering board solutions) and signal processing, principally inter-arrav correlation, while "clearly non-threat" are data-processed only from then on. (Note that in this experiment, since the acoustic data base is analyzed data, any large signal processing required is done remotely, at contractor's facilities or the ARC, and not necessarily in real-time.)

(C) The operator then proceeds to the next most visually striking signature and repeats the sequence exactly until every discrete frequency in the parameter estimation table for this beam has been accounted for as either a main-lobe or side-lobe detection. The control algorithm will not permit him to advance to the next beam until he has accounted for every discrete frequency in the beam being analyzed. He continues from left to right until all discrete frequencies on the seven beams for the forty minute period are associated with one or another harmonic series.

(C) In the third stage, he attempts to group individual harmonic sets into ships' signatures. Often this will be done on the basis of observations of similarity of estimated position, direction of movement, or rough bearing rate of change. This kind of information is displayed to the operator for interpretation and trial solution.

(C) Upon completion of the third stage, all signals present have, theoretically, been associated correctly with individual ships detected. A steady state algorithm monitors the static solution for changes, particularly changes which affect the credibility of the current solution. Changes are reported to the operator for confirmation or appropriate action.

(C) Having reached steady state, the operator returns to channel 1 to begin the sequence anew with display of the next time increment. However, his interaction is expected to be minimal since he is required to interact only to the extent that signals detected are not accounted for by the steady state algorithm.

(C) Signature Formation Logic

The paragraph numbers referenced below correspond to the entries in the third level functional logic diagrams, Figs. 4 through 7.

Non-Ship Clutter (NSC) Removal (Fig. 4)

1.0 (C) The operator displays the broadband (10-150 Hz) lofargram on the first beam. At this point he is attempting to recognize interfering signals not generated by ships. The system design philosophy is that these kinds of interfering signals, station artifacts, man-made ocean noise and sea noise are visually recognizable to an operator, usually without even the necessity of making a frequency measurement.

1.1 (C) Since many of these kinds of interfering signals appear simultaneously on many or even all beams of an array, the operator reinforces his classification by displaying all seven beams simultaneously on the face of the CRT. The display consists of 5 minute segments of each of the seven beams in beam number order from top to bottom of the screen. Start time for each segment is the time indicated interactively by the operator.

2.0 (C) Since it may be desirable to display examples of a particular type of non-ship clutter to allow the operator to make a direct visual comparison between the present interfering signature and a library of similar interfering signals, a photographic information retrieval system was incorporated as an option. In this system, the algorithm not only identifies the type of non-ship clutter, but also displays the address or storage location of examples of that type. The actual display was intended as an "off-line" function. Examples to be displayed were controlled by the operator who decides whether or not to display a particular image. The implementation contemplated was a photographic information retrieval system, perhaps one using microfiche image storage. It is essentially a memory jogger which prompts the operator to the most likely source of non-ship clutter.

3.0 (C) The operator indicates on the face of the broadband CRT display, enough components of the candidate NSC so that the algorithm can identify any others and confirm as non-ship clutter. It was anticipated that some non-ship clutter, particularly sea-noise, would require special interactive techniques, for example, multiple indications in the time domain in the case of the sea-noise phenomenon known as "commas", to establish the periodicity of these signals for consideration by the algorithm.

(C) The form of the interaction is that the operator "points" at the signal or signals on the face of the CRT by touching them with a "sonic pen", a device resembling a ball-point pen which contains a spark gap in the tip across which a hypersonic signal with an expremely short rise time jumps when the tip is depressed on a surface. Two orthogonally mounted pairs of linear microphones, each 14 inches in length, receive the resultant spark. Internal circuitry converts arrival time into X and Y coordinates in the 14" X 14" area to a resolution of as much as 4000 X 4000 points. Sonic pen interaction, thought of as simply an extension of a man's pointing finger is expected to be a natural and convenient method. Parallax problems resulting from curved tube faces, or simply operator inaccuracy were to be handled by the interactive control algorithm. Technical details of the sonic pen are discussed in Appendix A.

3.1/3.2/3.3/3.4(C)System design anticipates that the operator, recognizing non-ship clutter is able to go one step farther to the point that he is able to categorize it tentatively as one of the three generic classes of non-ship clutter. At this point, the operator is heavily interactive with the system. He makes the selection of most likely type of non-ship clutter, and on completion of the algorithm's evaluation, gets the opportunity to concur or not concur. Note that the operator's options at this point are:

1. to accept the algorithm's judgment that the signal is non-ship clutter and continue to the next non-ship clutter signature, (which may be on another beam), or, if there are no others, continue on to harmonic set formation, or,

2. disagreeing with, or being unconvinced by, the algorithm's decision that the signal is not a recognized type of non-ship clutter, he can provide additional signature clues, perhaps from higher resolution displays, or, he can select a search through one or both of the other generic non-ship clutter paths.

The one thing he cannot do, however, is override the algorithm and declare a signal to be non-ship clutter if the algorithm decides otherwise. Such signals are carried as if they are ship detections. The reasoning that went into this design feature is that it is more desirable to suffer a temporary (until the algorithm can be updated) increase in false target loading than to permit subjective interpretations (i.e., classifications) at this point to cause false dismissal of a real target signature.

The principal types of non-ship clutter considered in the initial design were those given in Chapter 3 of reference 4.

4.0 (C) All identified non-ship clutter is tagged as accounted for in the parameter estimation table for each resolution, and displayed multi-beam in the format of Section 1.1, above, with the exception that non-ship clutter signals are labeled with a cross stroke on the display. This sequence continues if the operator wishes to test for the presence of other non-ship clutter.

5.0 (C) A high-risk effort designed to eliminate identified non-ship clutter from the display was to be undertaken on a not-to-interfere basis. The intent was to change all intensity words in the time-frequency rectangle enclosing the non-ship clutter to zero intensity, and then substitute pseudo-random noise in that interval. Some of our prior experience in this area indicates that this technique sometimes leads to a more confusing display.

(C) <u>Harmonic Set Formation (Fig. 5)</u>

1.0 (C) Having identified all known non-ship clutter on all beams, the operator next tries to form independent harmonic sets from the remaining discrete frequencies. The approach is to use the pattern recognition powers of the human to reduce the complexity of the organizational problem by attempting to organize the most visually evident harmonic set first, then continue to the next most visually evident, and so forth, until all discrete frequencies are accounted for.

(C) The technique employed is to have the operator point at the minimum number of components necessary to determine the fundamental, normally two adjacent harmonics, although he can indicate more, or less, in the case of a single-line signature. The algorithm makes a frequency determination for each operator indication.

2.0 (C) The frequency obtained is the value in the parameter estimation table, not the exact value that would be calculated from the position of the interactive device. In cases where the operator indication is not on a displayed frequency, whether through parallax or hasty or inattentive action, the algorithm selects the nearest frequency in the table. In this case, as in the case of an indication which might refer equally well to two frequencies, e.g., one equidistant between two signals, the algorithm's results are displayed to the operator for concurrence. Whenever an uncertainty arises at this stage, the operator can cause displays at vernier and super-vernier resolution to permit observation of minor dynamics or closely spaced signals. A multiple band display permits side by side (time-synchronized) high resolution display of several narrow bands simultaneously. Since the accuracy of the frequency indication is that of the front end signal processor the mean square error characteristic of that particular system will be used initially in testing validity of harmonic set formation.

2.1/2.2(U) Calculation of the fundamental frequency is accomplished by subtracting the lower of two frequency entries from the higher, or, if more than two are entered, the minimum difference is calculated. We had given some thought to a procedural requirement that the first two interactive entries must represent the harmonic spacing, but concluded that this was both undesirable and unnecessary. The fewer constraints on ther operator's actions, the better.

2.2 (C) The algorithm tests that all signals indicated are integral harmonics of the fundamental frequency. If any are not, this information is displayed to the operator, and he is permitted to delete those in error for this particular harmonic set, or return to step 1.0 if the solution is grossly in error. The algorithm attempts to expand the solution by accessing the parameter estimation table for that beam and time interval in search of discrete frequencies which, arithmetically at least, are part of the indicated harmonic series. Candidate harmonics are indicated on the acoustic display by means of a slash (\). Acceptance by the operator results in tagging in the parameter estimation table and completion of the indiation on the acoustic display by a superimposed reverse slash (/) - i.e., combination

/ +\ = X. The operator is permitted to reject candidate harmonics, in which event the parameter estimation table entry is available for consideration as part of another harmonic set.

2.3 (C) Candidate harmonic sets detected on one beam will frequently be detected on other beams as well. The algorithm, making use of the harmonics identified thus far, attempts to find other beams with more harmonics or the same harmonics with greater relative signal-to-noise values. Algorithm identification of a different beam as best beam satisfies the requirement for accounting for each discrete frequency on one beam before moving on to the next beam. An algorithm decision that this harmonic set is actually on another beam results in a multi-beam lofar display permitting the operator to concur or not concur and to accomodate situations where the pattern recognition capability of the operator can be employed to resolve ambiguities not clearly resolved by the algorithm - e.g., the case where interfering signals temporarily mask the signature on the beam being examined.

3.0 (C) When it has been determined that this is the best beam for this harmonic set, the baseband lofargram is displayed with all harmonics identified by the man-machine combination labeled.

3.1 (U) The operator has the opportunity to correct or expand the solution, i.e., on the basis of observation of the display either to delete additional harmonics supplied by the algorithm or to add additional harmonics not supplied by the algorithm. (An example of the latter might be discontinuous signals.)

3.2 (U) The operator is required to concur in the solution at this point. If he made a correction or expansion, the change must be verified correct by the algorithm.

3.3 (C) The pivotal decision point in the signature formation process is the point at which the operator decides that he is, or is not, satisfied with the solution thus far - a solution based largely on measured frequency, observed dynamics, and rough bearing compatibility. In the event an ambiguity or uncertainty arises, he goes to that part of the harmonic series formation sequence that involves the greatest amount of operator interaction and the execution of special purpose signal processing algorithms. The percentage of time that the use of signal processing algorithms for ambiguity resolution will be required is not known. However, it seems likely that most harmonic set formation can be done by frequency-based operator interactive techniques alone, particularly in the case of harmonic-rich signatures which comprise the largest part of the interfering clutter.

3.3.1 (C)(Figure 5B) The operator selects that ambiguity resolution path which addresses the specific uncertainty encountered. We anticipate that the most important of these will be in the areas of bearing and minor dynamics, although five other characteristics (amplitude, phase, harmonic emphasis, bandwidth, and stability consistency) will be considered. No signal processing development is being done as part of this experiment. The signal processing algorithms shown in Fig. 5C have been developed by Navy Laboratories or contractors, and are to be available for execution either at the ARPA Research Center or other remote facilities. It is not necessary that they be executed on demand by computer to computer link. Ambiguity resolution by signal processing involves a two-step decision process. The operator first selects one of seven characteristics he wishes to consider. Next, he chooses, consecutively, those signal processing algorithms capable of resolving that particular ambiguity. (In this experimental approach, the intent is to exercise <u>all</u> available algorithms capable of resolving <u>each</u> ambiguity and so evaluate the potential of each.) The objective is to identify the minimum signal processing package required to provide an acceptable confidence level for association of detected signals. In the current experiment, since the signal processing algorithms are, in fact, exploratory developments, whose operational deployment potential is unknown, operator concurrence with the result of a particular algorithm is required.

3.3.1.1(C)Bearing sorting is highly significant in harmonic set formation - if the candidate components have different bearings they are clearly not from the same noise source. The results of execution of the bearing determination algorithms are displayed for operator concurrence. The exact value of the confidence factor assigned is determined by the design of the particular algorithm, within its range of effective operation, until and unless empirical evidence indicates otherwise. In the case where bearings are clearly not compatible, those components cannot be formed into either the same harmonic set or the same ship's signature.

3.3.1.2(C) Resolution of time-dynamic ambiguity is the next most important consideration. A clear mismatch on dynamics prevents inclusion of the candidate components in the same harmonic set, but does not necessarily preclude their being linked in the same ship's signature.

3.3.1.3(C) Although the characteristics tested (amplitude, phase,
3.3.1.4 harmonic emphasis, stability and bandwidth) are thought
3.3.1.5 to have less relative significance than the bearing and
3.3.1.6 dynamics tests, each will be tested to try to establish
3.3.1.7 a maximum confidence score. The technique is, in general, the same as in 3.3.1.1 and 3.3.1.2 except that, since the significance of these measurements is frequently uncertain, a candidate component will not be rejected for either harmonic set or ship signature compatibility on the basis of a "no consistency" result. That is, the significance, if any, will be determined experimentally.

Summarizing the effect of the seven tests:

a. bearing inconsistency prohibits both harmonic set <u>and</u> signature formation,

b. dynamic inconsistency prohibits harmonic set but <u>not</u> signature formation, and

c. all other inconsistencies merely lower confidence in harmonic set or signature formation but prohibit neither.

When the operator has completed a test of all ambiguities, or if no useful purpose would be served by addressing the remaining characteristics, he gets a display with a statement of the degree of confidence with which the candidates have been associated.

3.5 (C) Bandwidth, stability, and harmonic emphasis are determined by accessing the parameter estimation table of the front-end signal processor (spectrum analyzer) utilized. The precise analysis system used is of no particular consequence - several are suitable - provided only that analysis bandwidths approximating SOSUS broadband, vernier, and super vernier are available, and that signal characteristics are estimated and available in tabular format.

3.6 (C) This section represents the simplest kind of classification algorithm - i.e., "twenty-questions" or serial logic. In fact it serves, not as a classification algorithm, but as a "negative classifier", or filter for non-interest signatures. Each decision diamond in the diagram represents a comparison of the harmonic set present to known limits in the operating characteristics of targets of interest. The comparisons are objective, based only on the frequency and harmonic emphasis characteristics of the particular harmonic set. Subjective interpretations, for example, estimates of the source, i.e., the rotating machinery producing the signal, are not permitted.

(C) The significance of this test for threat potential is that signals having any threat potential whatsoever are localized, if possible, using both data and signal processing algorithms, while those having no threat potential are not localized, but merely have their best beam identified.

3.7 (C) Harmonic sets meeting the minimum threat potential requirements are to be localized. As a practical matter, the initial localization effort with no bearing history available, and simultaneous multi-station contact unlikely, will almost always result in storing the best beam or bearing only. If there is a bearing history, algorithms utilizing bearings, times, and estimated speeds of advance will be executed. If there is multi-station contact, coherent signal processing algorithms will be executed for simultaneous detections meeting the signal input requirements for these algorithms. In all other cases, multi-station localization data processing techniques will be used. Depending on the success of the localization algorithms, the formed sets have either an estimated position or best beam/bearing stored in the threat accounting table.

3.8 (C) Upon completion of the localization attempts, the system requires that all discrete frequencies in the parameter estimation table of the beam being processed be accounted for either on that beam or as side lobe detections from another beam. Advancing to the next beam while one or more frequencies are unaccounted for is not permitted. When all frequencies on that beam are accounted for, the operator advances to the next beam and continues to form harmonic sets, unless he has processed the final beam in which event, he goes to the next major phase - combining independent harmonic sets into the signatures of individual ships. Note that the organizational concept employed is that <u>all</u> harmonic sets are formed before the first ship's signature is formed.

(C) Ship Signature Formation (Fig. 6)

4.0 (C) The objective of this function is to combine separate harmonic series into the signature of a ship, where those series may be dependent, i.e., related by some fixed ratio, or independent. In most cases, we anticipate that combination will be done on the basis of similarity of position or tracking characteristics. In some number of cases, it may be possible to combine harmonic sets on the basis of measurable or observable acoustic similarities.

4.1 Three displays are used by the operator in varying combina-
4.2 tions and sequences to discover characteristics common to
4.3 two or more harmonic series. These displays are:
4.4

a. Geographic - A plot of bearing vs range for harmonic series successfully or tentatively localized. This display also plots harmonic set number vs range.

b. Azimuth - a plot of bearings vs series held on that bearing. A more detailed alpha-numeric display accompanies this plot.

c. In/Out - a plot of detection intervals for the strongest component for each series on a particular beam or bearing.

An example serves to illustrate a likely sequence. (Fig. 6B)

The operator calls for the azimuth display and notes that harmonic series labeled A, D, and F are on the same bearing. A and D, clearly non-threat signatures, have not been localized, but F, with some threat potential, has been localized for 5, 10, and 15 knot speed estimates. A display of detection intervals for A, D, and F reveals that A and F have simila time histories. The operator attempts to localize the non-threats A and D, using the previously assumed speeds, - vs other appropriate speeds if the situation warrants. A is determined to have a position and general directior of movement similar to F, while D has little track correlation. The logical inference is that A and F combined are candidates for the ship's signature. The more consistencies, of course, the greater the probability that the inference is the correct one.

4.5 4.6 (C) An attempt is made to confirm relationships suggested by tracking and localization similarities uncovered in 4.1 through 4.4 through the use of signal processing resources. Specifically, frequency trackers are assigned to the strongest harmonic in each of the two series to try to establish frequency excursion consistency, in terms of direction of excursion, or, better, the existence of a fixed frequency ratio between series. A second signal processing approach seeks to establish constant phase relationships between the two series.

4.7 (C) Since the reliability of conclusions based on minor dynamics and phase signal processing is questionable, the operator is given a multi-beam display of the candidate solution and is required to concur or not concur. Until such time as the reliability of these signal processing algorithms is certified, the operator's concurrence is required before candidates for combination are accepted by the system as harmonic series from the same ship.

4.8 (C) When two or more harmonic series are combined in a ship's signature, the position assigned to that signature is that which corresponds to the highest confidence localization of any of the series.

4.9 (C) The negative classification algorithm applied in the harmonic set formation phase is reapplied. Series which alone have threat potential, when associated with one or more clearly non-threat series, become clearly non-threat ship signatures. Depending on the threat potential of the newly combined series, the signature is stored in either the threat or non-threat file. The significance of this is that when contact is lost on signature components in the non-threat file, no signal processing action is taken, while the same condition (i.e., lost contact, not just loss of a component) in the threat file results in automatic high resolution signal processing in an attempt to regain contact.

5.0 (C) An alpha-numeric display of all current potential threats is presented to the operator. Before entering the Steady State phase, frequency and geographic trackers, as available, are assigned by the operator to retain contact and refine position and track estimates.

5.0 (C) The Steady State Solution

(U) This phase is characterized by a high degree of automation whose purpose is to maintain and refine the solution developed during the operator-interactive phase with a minimum amount of recourse to the operator interactive mode.

5.1 (C) The Steady State algorithm continually monitors for changes in the Steady State Solution by comparing the most recent formed signatures in the threat and non-threat descriptor tables to the latest output of the front end signal processor in the parameter estimation table. The changes fall into one of four general categories:

a. loss in harmonic set member(s)
b. gain in harmonic set member(s)
c. change in signature characteristics
d. change in target position, tracking, or maneuvers

5.1.1 Loss in Harmonic Set Member(s)

(C) Loss of one or more components of a non-threat signature is a desirable event in that it reduces non-threat interference. Loss of such components causes the non-threat descriptor table to be updated. Where the loss reflects target movement, i.e., components lost on one beam are now detected on another, a new "best-beam" determination is made and the table so modified. Since the ratio of well-defined, harmonic-rich "clearly non-threat" signatures to "potential threats" is, conservatively about 10 to 1 in the SOSUS and the ratio to actual or "probable" threats is much higher still, it should be possible to account for losses in harmonic sets almost totally automatically without recourse to operator interaction except in rare cases.

Potential threat signatures are handled differently. A loss of one or more harmonics of a potential threat causes an immediate alpha-numeric display advisory to the operator, stating not only the specifics of the loss, but also the processing resources available to attempt regaining contact. The operator's action is not determined by algorithm. Loss of a single component may have no special significance except in the unusual case where that component is the only one held simultaneously by another array. An acoustic display allows the operator to note visually the difference in signature appearance before and after the component loss.

(C) Where it is desirable to apply signal processing resources for reacquisition, the operator specifies the type and number of channels to be used and the reacquisition search plan.

(C) A successful reacquisition, e.g., by a frequency tracker or high resolution analyzer, requires operator concurrence and results in either an update of the threat descriptor file for concurrence or return to harmonic set formation for non-concurrence.

(C) The operator, as a result of an unsuccessful re-acquisition attempt, can direct the application of other signal processing resources, or the continued application of the previous ones for a fixed period of time.

(C) Loss of components in a high potential signature causes the operator to return to harmonic set formation to maximize the probability of reacquisition. It is likely, however, that in the case where the loss of one or more components still leaves a well-defined signature, the operator will opt to return to steady state as in the case of a low threat potential signature.

5.1.2 Gain in Harmonic Set Member(s)

(C) New detections are compared to existing signatures primarily on the basis of frequency and bearing information. Successful matches result in both an alpha-numeric advisory message, and an acoustic display indicating the harmonic(s) gained and the candidate solution, which requires operator concurrence. Detection of new, unrelated components results in immediate exit from steady state to harmonic set formation. Past experience indicates that most new detections are associated with existing signatures.

5.1.3(C) Change in Signature Characteristics

(C) A change in signature characteristics noted by comparing the values in the latest parameter estimation table to the previous entries causes execution of the negative classification algorithm. Examples of changes are: a) a change in harmonic emphasis, b) a change in the ratio of the fundamentals of two harmonic sets. These kinds of changes have the effect of converting threats to non-threats and vice versa, or of increasing or decreasing the threat potential, of a possible threat. The operator's concurrence is required to update the target status tables, both threat and non-threat. In the case where the operator disagrees with a non-threat to threat conversion, he is required to examine an acoustic display, and is permitted to call for execution of ambiguity-resolving signal processing resources.

5.1.4(C) Changes in Target Localization, Tracking, Maneuvers

(C) Both threat and non-threat signatures are checked for correctness of the original solution on a continuing basis. Where the signature consists of more than one harmonic series, both are checked for bearing consistency. For threat signatures, changes in the predicted track solution represent a change in the steady state. Abrupt loss of one or more series or frequency shifts indicating maneuvers, are recognized as significant changes. All result in a display to the operator and a requirement for an operator-interactive task - i.e., a decision as to the effect of the change on the particular signature's threat potential - and a modification, if appropriate, of the threat or non-threat file.

(C) At the point where Steady State has been reached, since change takes place slowly in fixed surveillance systems, and most changes reflect detections or losses of components of signatures currently held, it should be possible to maintain the Steady State Solution with a low operator task rate, where the tasks, options, and action required are objectively defined. A major purpose of this experimental development is to determine empirically, using real-world data, the operator task rate.

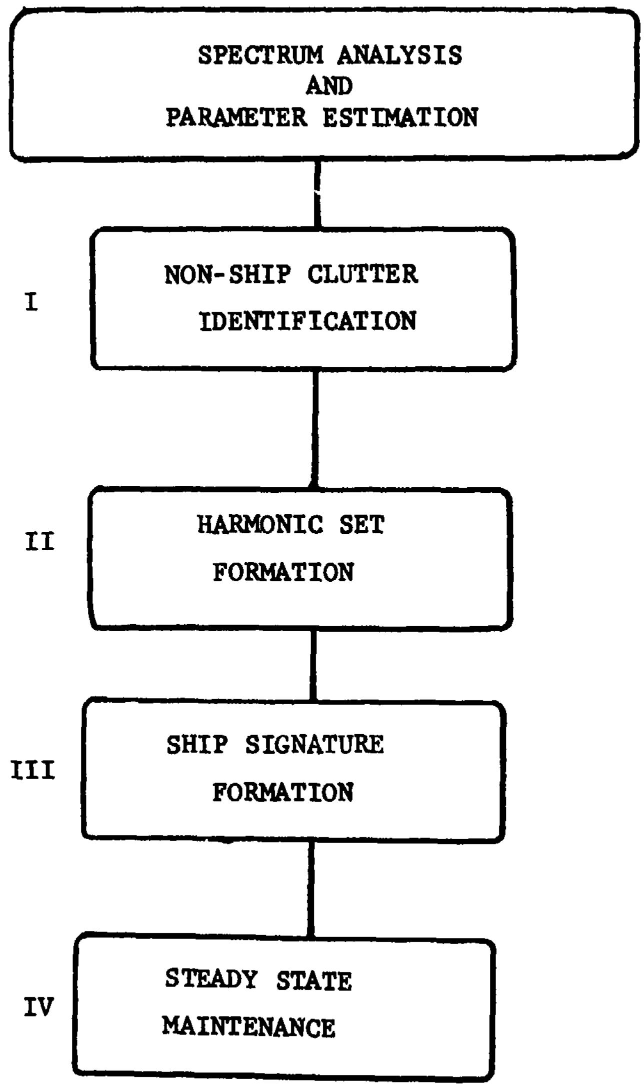
References

1. Operator/Machine Interactions for Sector Scan in Acoustic Undersea Surveillance - NRL Program Plan of 6 June 1975 (S).

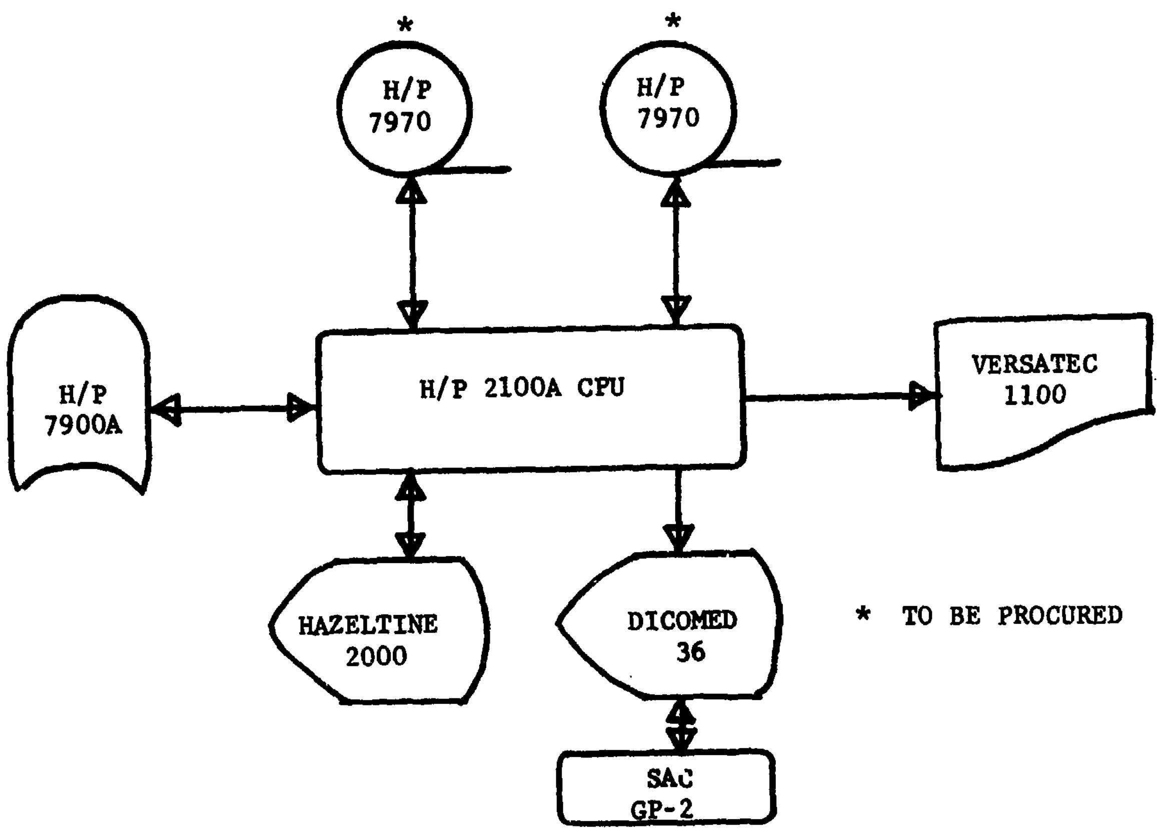
2. Automatic Signature Formation and Classification - NRL ltr ser C49 dtd 10 Feb 1977 (C).

3. COMOCEANSYSLANT LIMA Events 1972 and 1973. (George V. Olds, NRL) - Presentation to Automatic Detection/Automatic Classification Committee at NUSC, NLON June 1974.

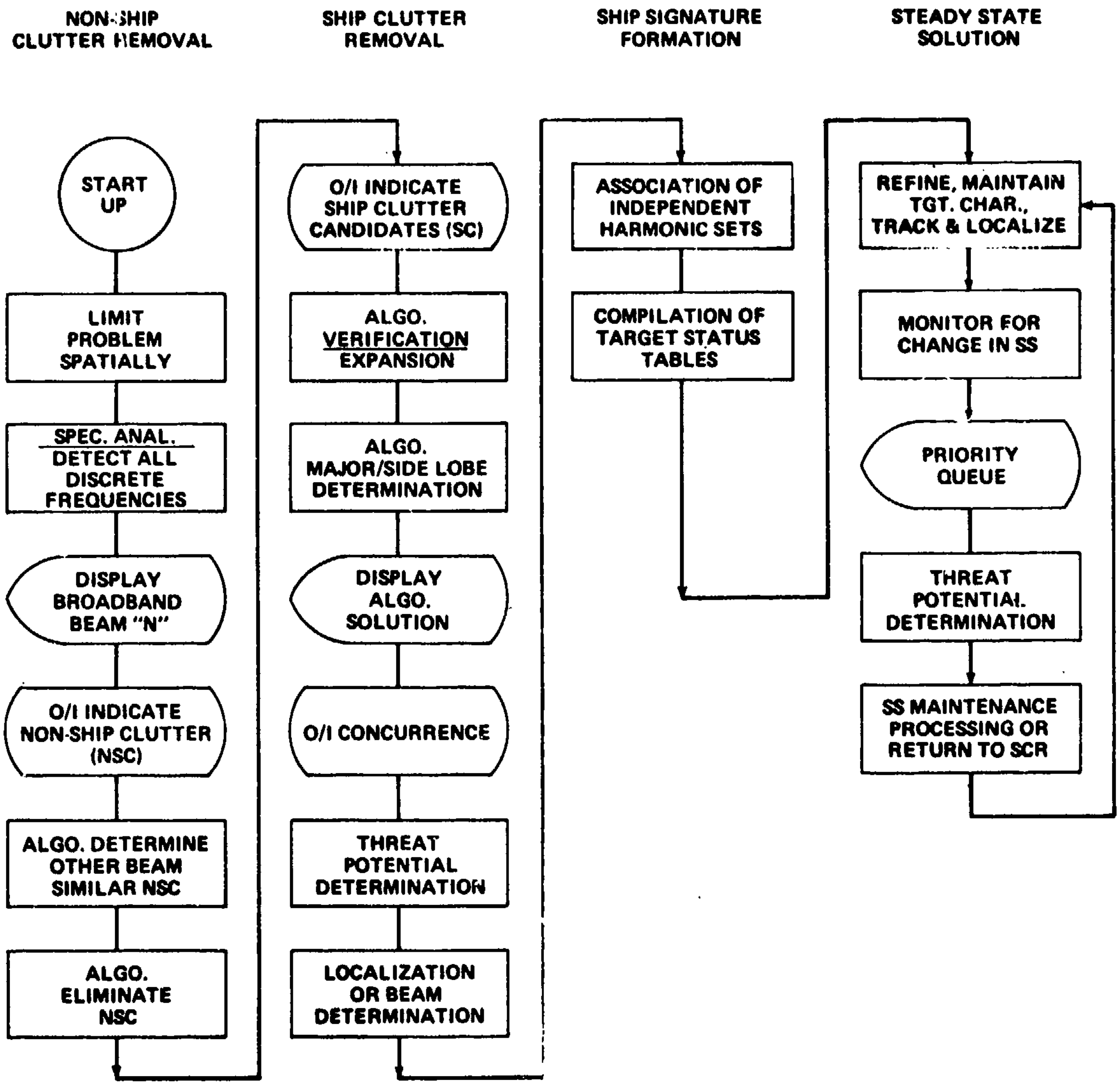
4. Principles of Lofargram Analysis, NAVSHIPS 0967-340-4010 (S).



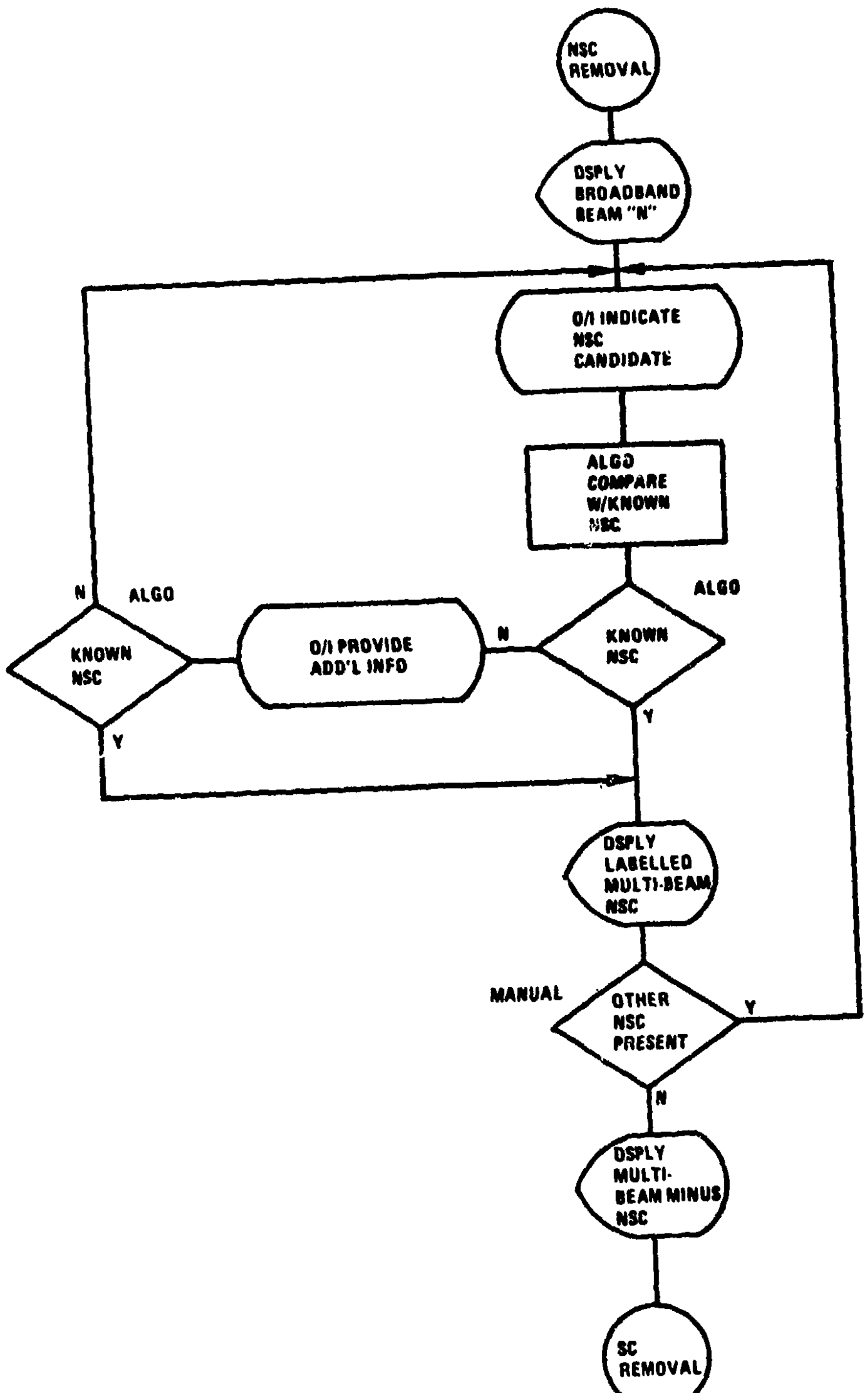
(C) Fig. 1 - Signature formation sequence



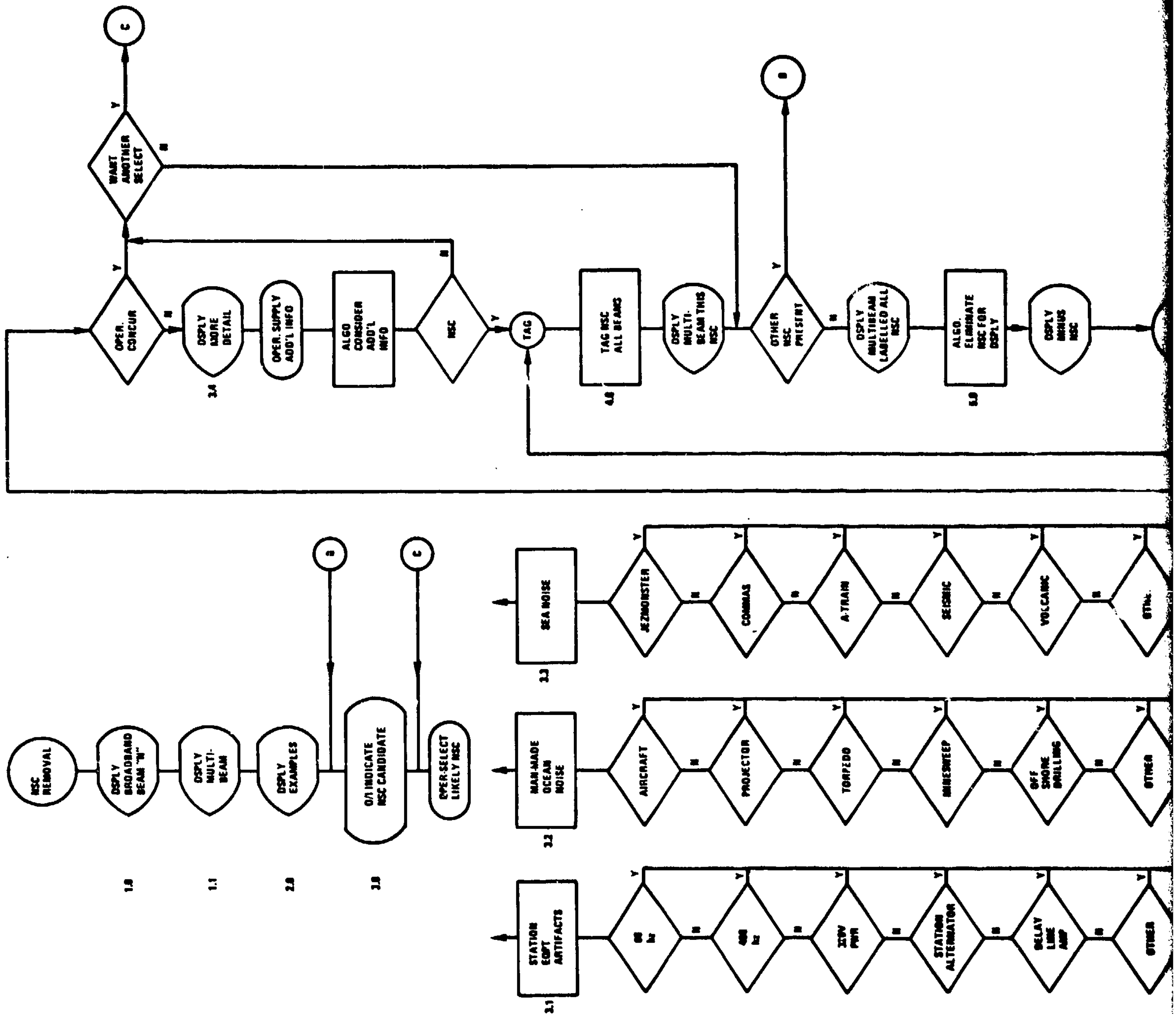
(U) Fig. 2 - Experimental configuration

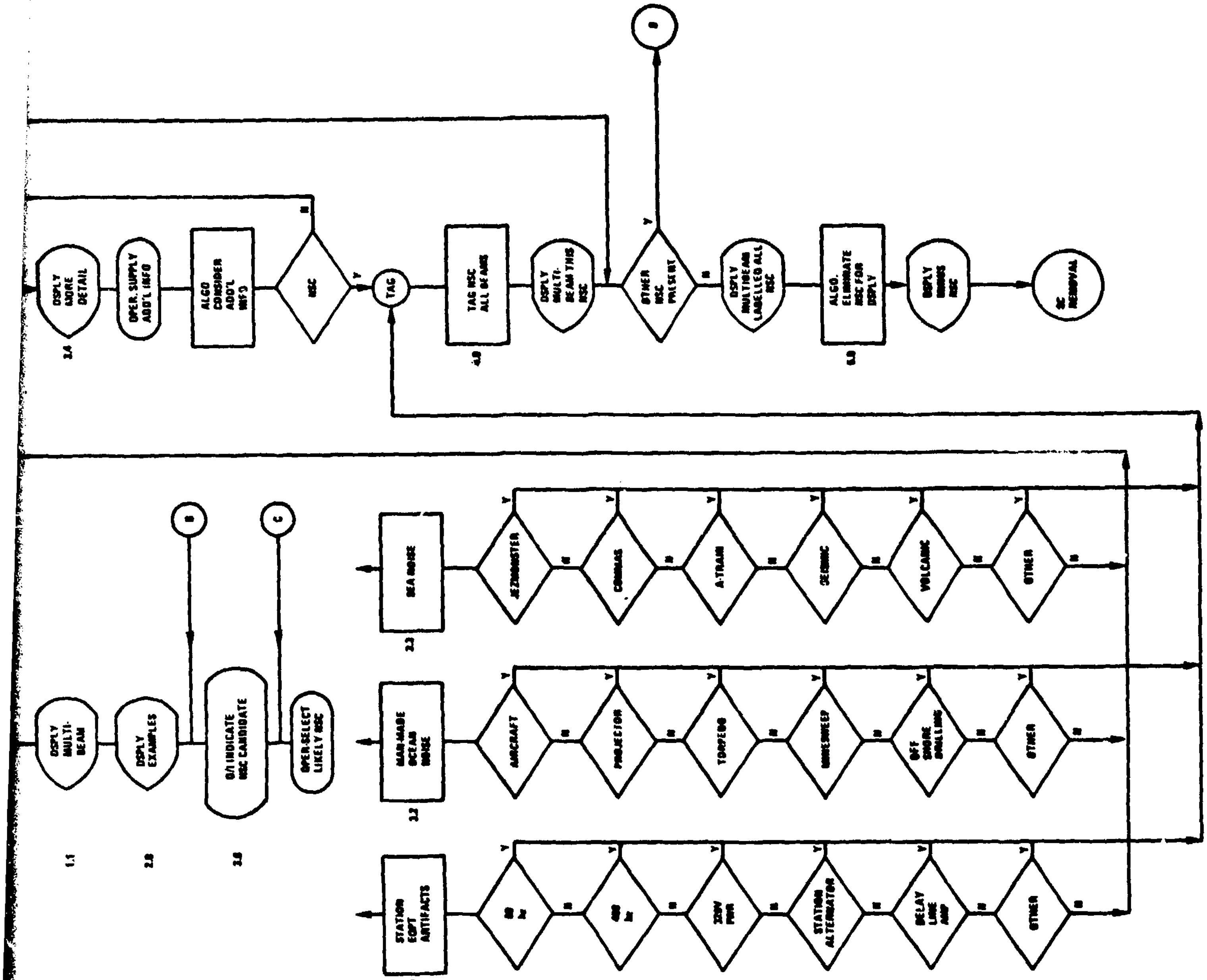


(C) Fig. 3 - Operator interactive signature formation overall logic



(U) Fig. 4 - Non ship clutter removal 2nd level diagram


C
B
WANT ANOTHER SELECT
OPER. CONCUR
DSPLY MORE DETAIL
3.4
OPER. SUPPLY ADD'L INFO
ALGO CONSIDER ADD'L INFO
NSC
TAG
TAG NSC ALL BEAMS
4.0
DSPLY MULTI-BEAM THIS NSC
OTHER NSC PRESENT
DSPLY MULTIBEAM LABELLED ALL NSC
ALGO. ELIMINATE NSC FOR DSPLY
5.0
DSPLY MINUS NSC
SEA NOISE
3.3
A-TRAIN
SEISMIC
VOLCANIC
MAN-MADE OCEAN NOISE
3.2
AIRCRAFT
PROJECTOR
TORPEDO
MINESWEEP
OFF SHORE DRILLING
OTHER
STATION EQPT ARTIFACTS
3.1
STATION ALTERNATOR
DELAY LINE AMP
OTHER
NSC REMOVAL
DSPLY BROADBAND BEAM "N"
DSPLY MULTI-BEAM
DSPLY EXAMPLES
O/I INDICATE NSC CANDIDATE
OPER-SELECT LIKELY NSC
1.0
1.1
2.0
3.0



(U) Fig. 4A - Non ship clutter removal 3rd level diagram

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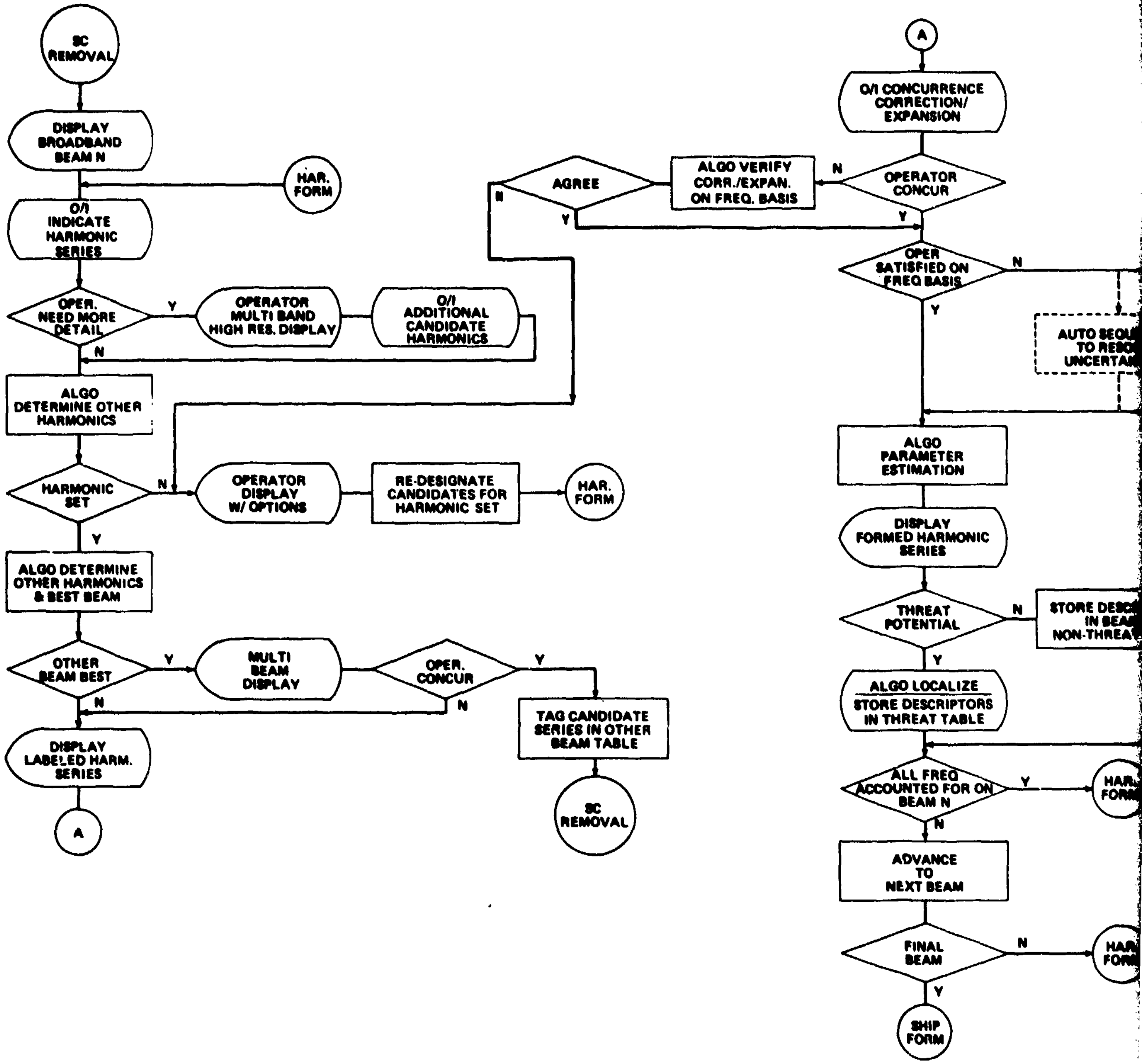
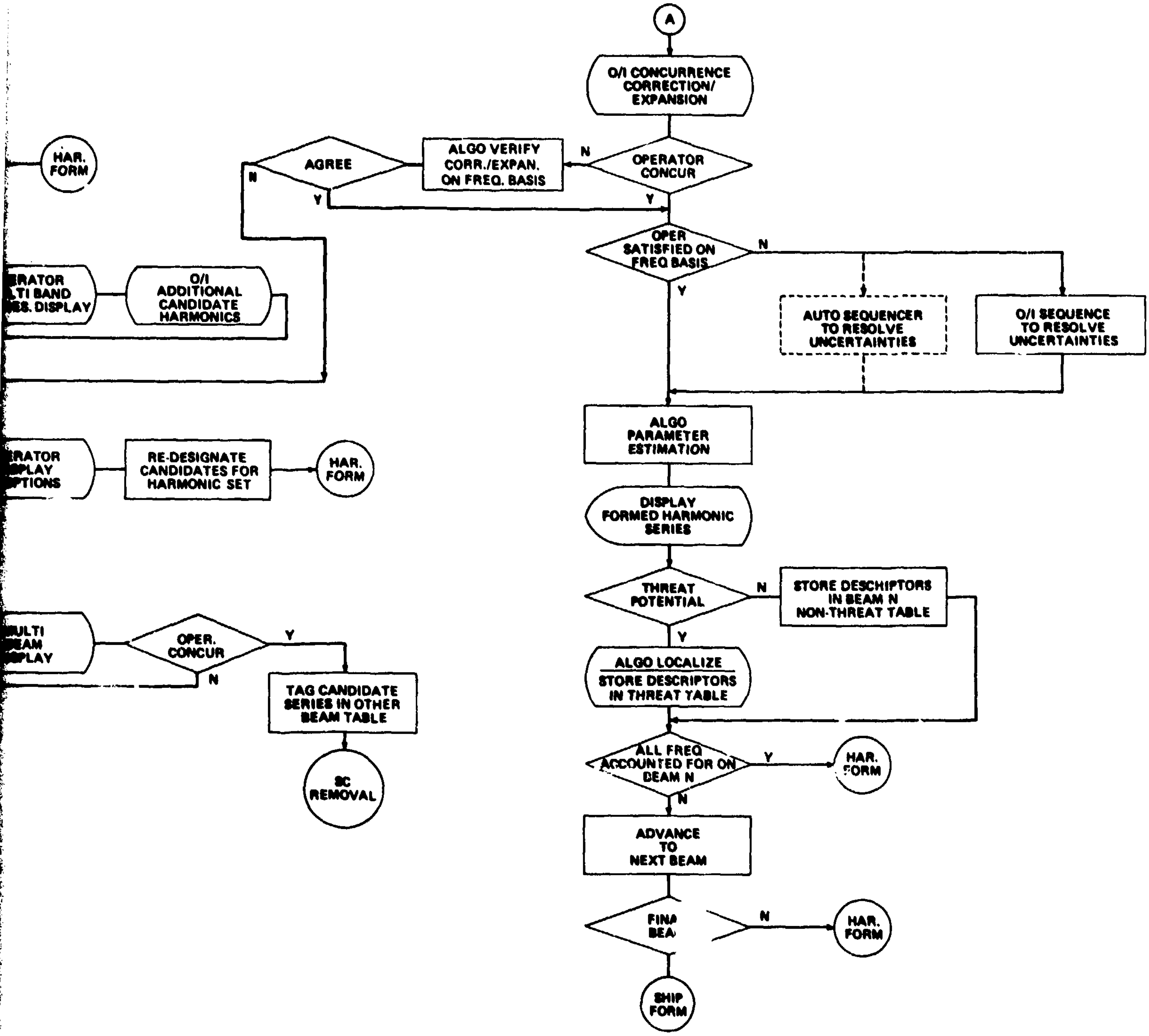
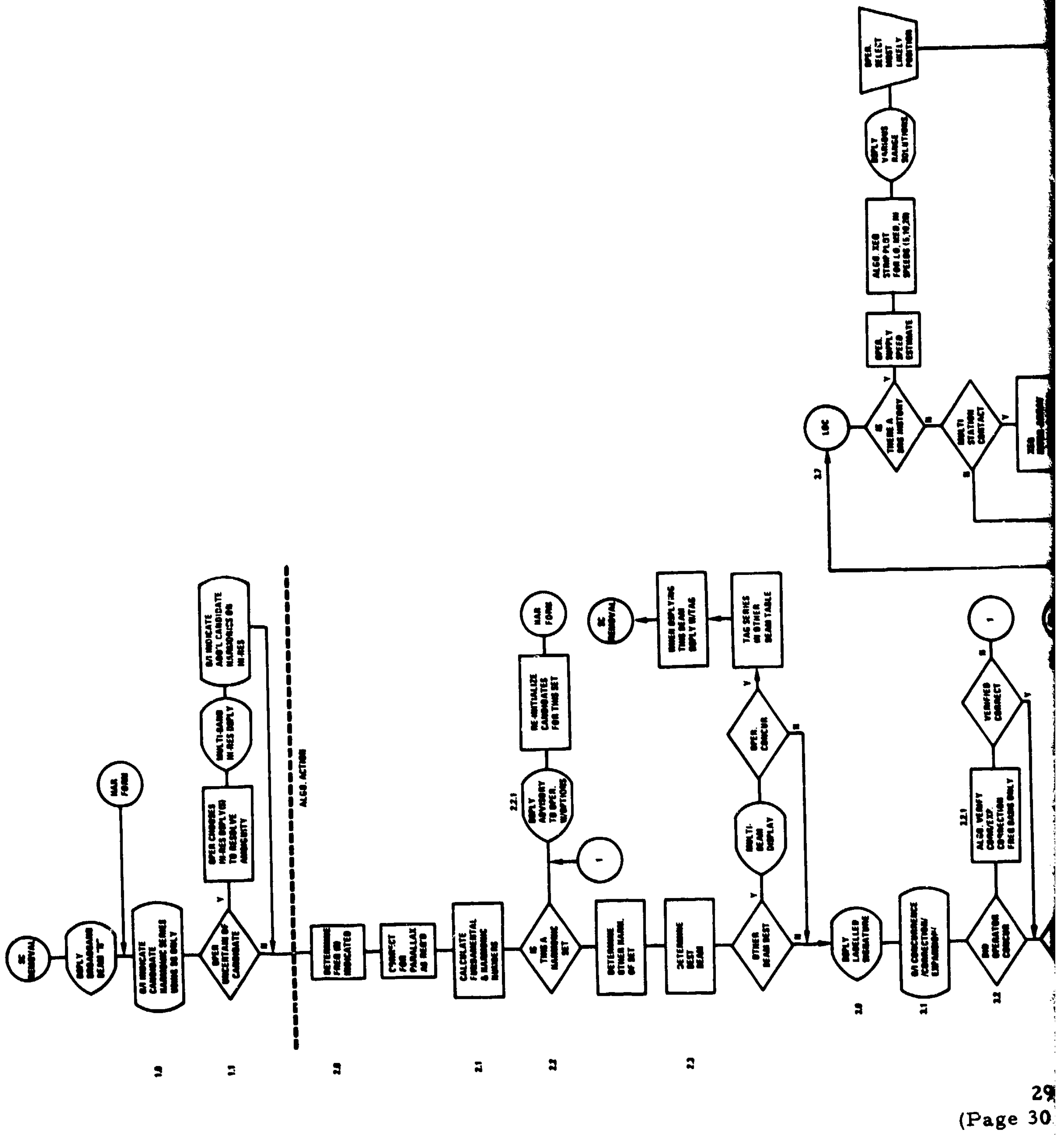
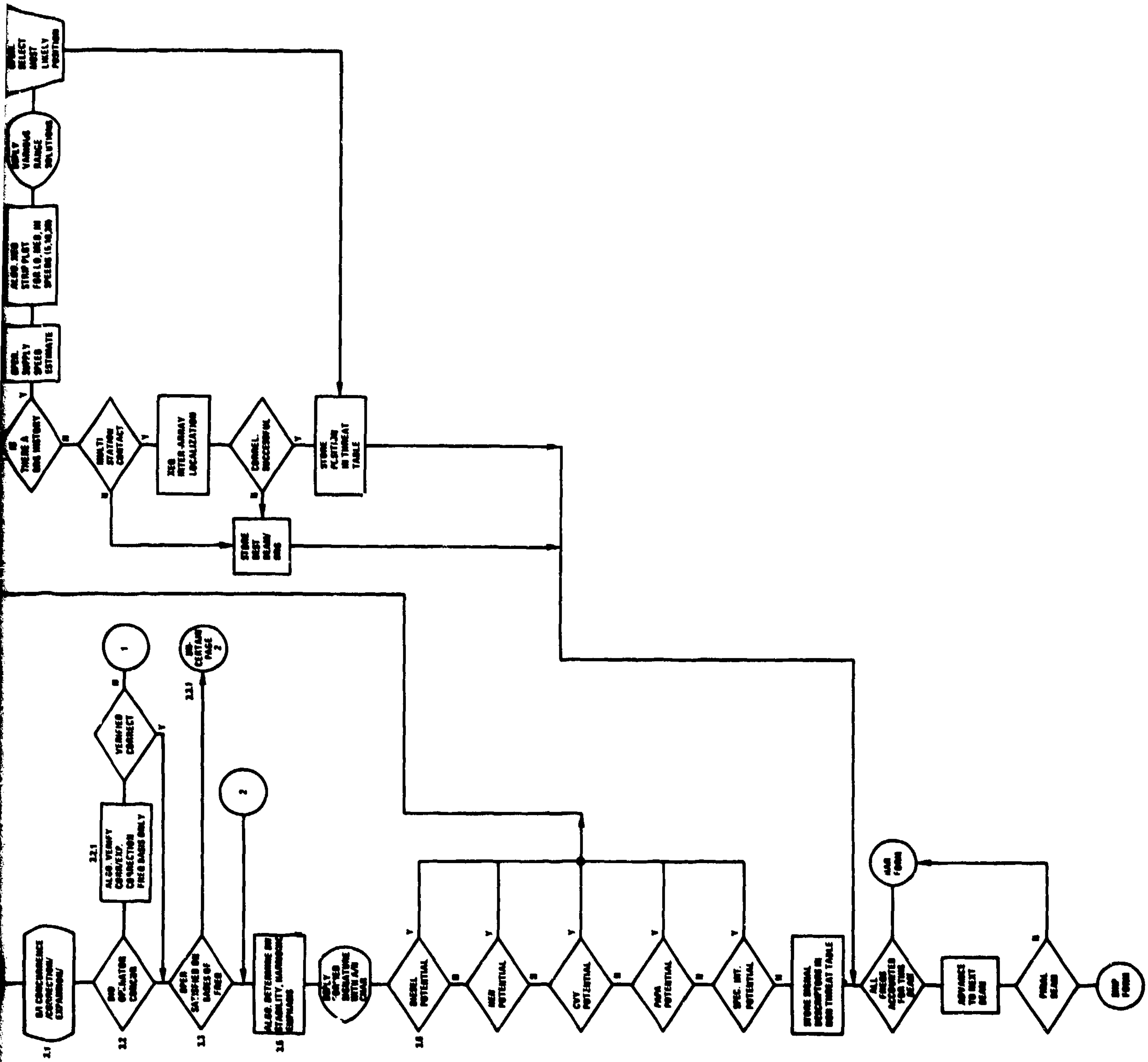


(U) Fig. 5 - Harmonic set formation 2nd level diagram



(U) Fig. 5 - Harmonic set formation 2nd level diagram





(U) Fig. 5A - Harmonic set formation 3rd level diagram (page 1)

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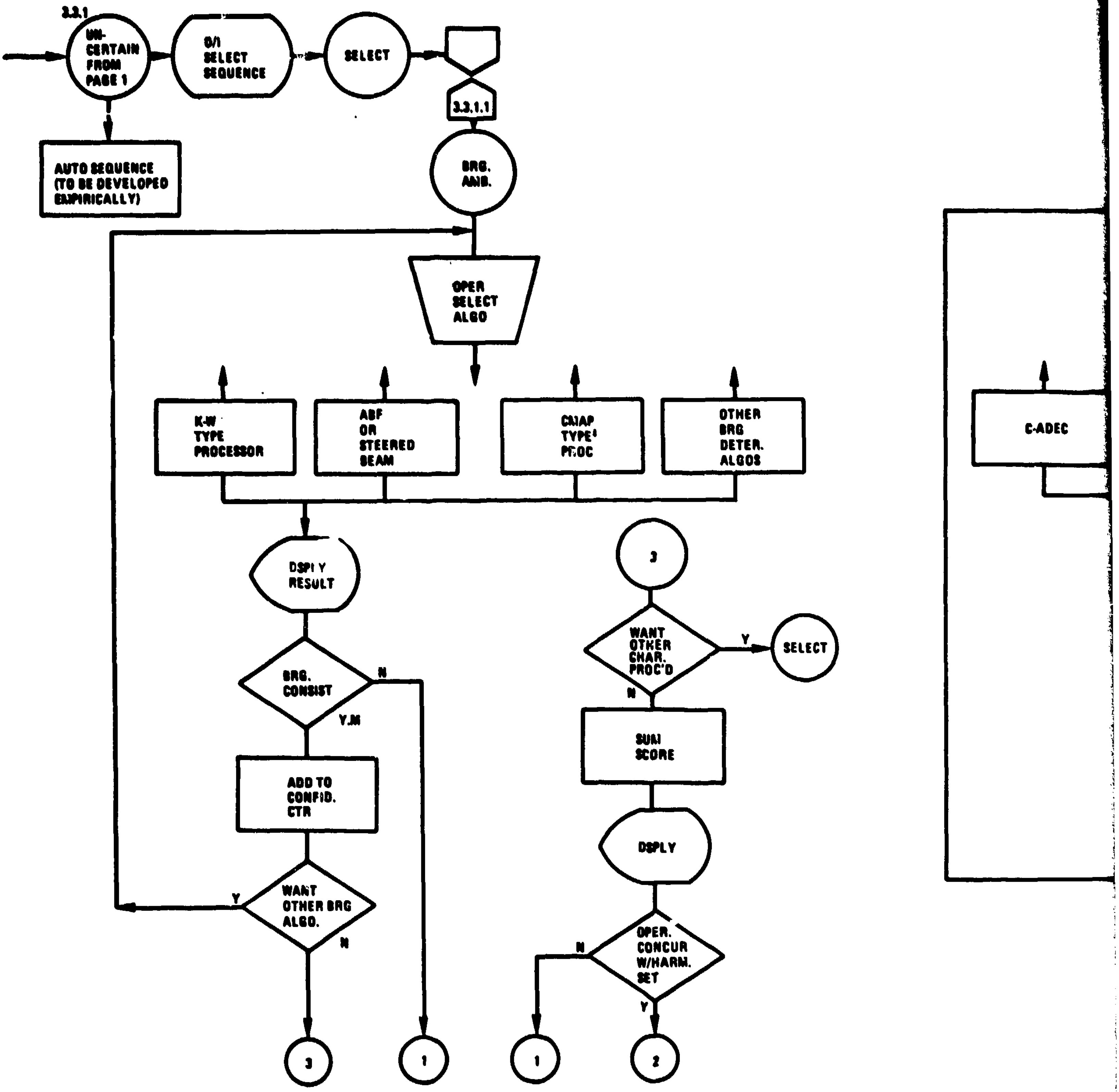
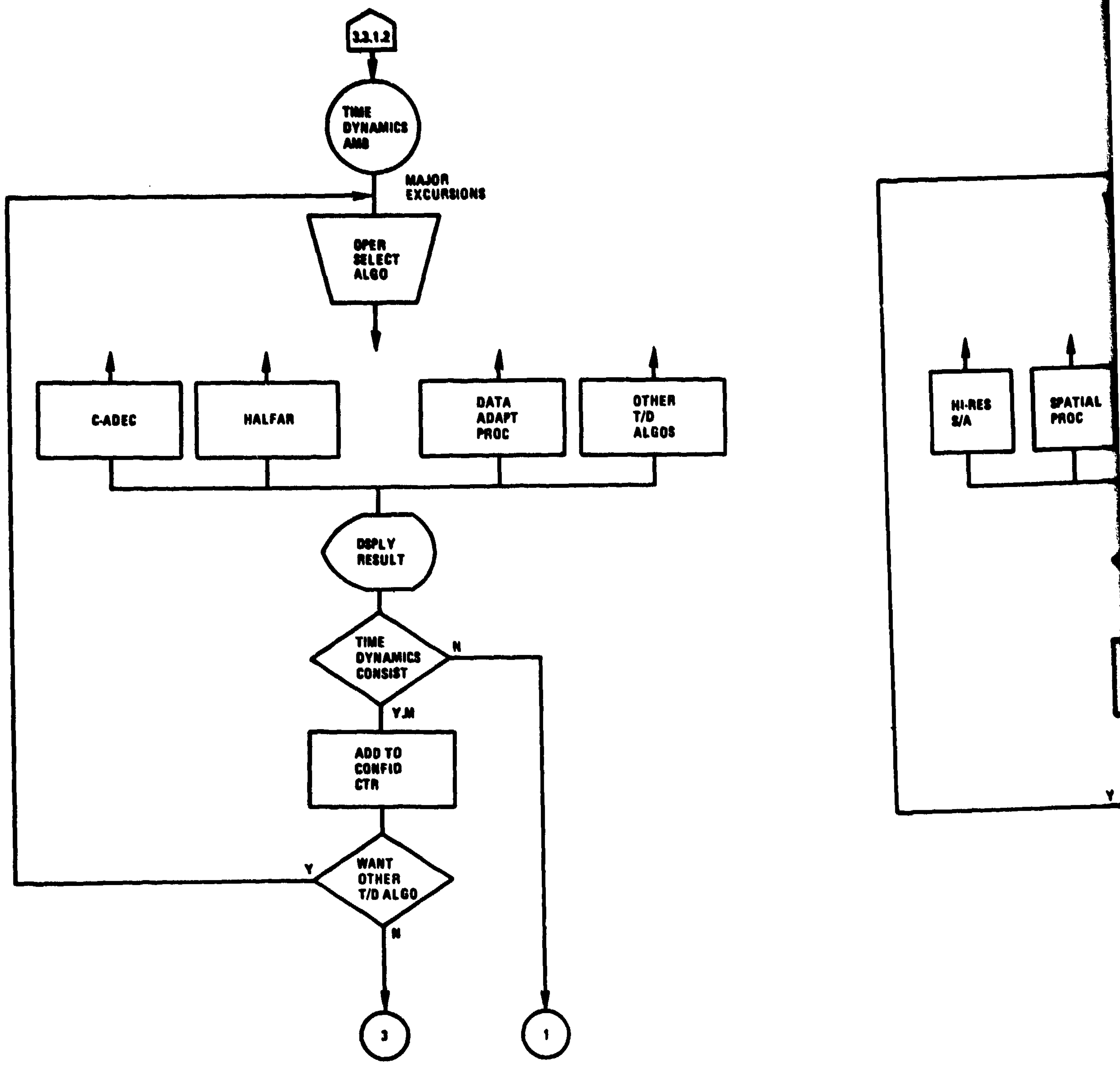
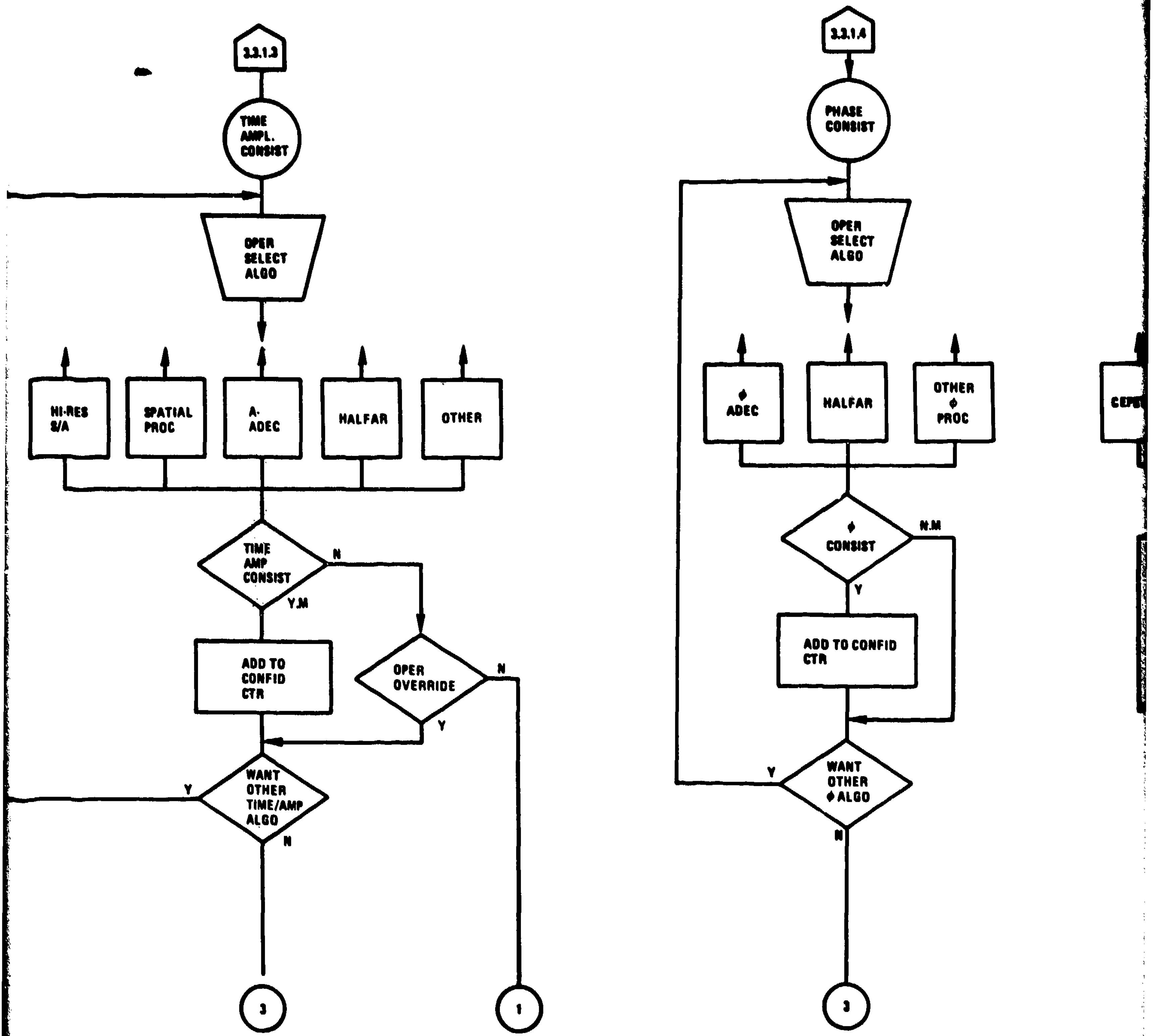

3.3.1
UN-CERTAIN FROM PAGE 1
O/I SELECT SEQUENCE
SELECT
3.3.1.1
AUTO SEQUENCE (TO BE DEVELOPED EMPIRICALLY)
BRG. AMB.
OPER SELECT ALGO
K-W TYPE PROCESSOR
ABF OR STEERED BEAM
TYPE PROC
OTHER BRG DETER. ALGOS
C-ADEC
RESULT
BRG. CONSIST
N
Y.M
ADD TO CONFID. CTR
WANT OTHER BRG ALGO.
Y
N
3
1
3
WANT OTHER CHAR. PROC'D
Y
SELECT
N
SUM SCORE
DSPLY
OPER. CONCUR W/HARM. SET
N
Y
1
2



(U) Fig. 5B - Harmonic set f

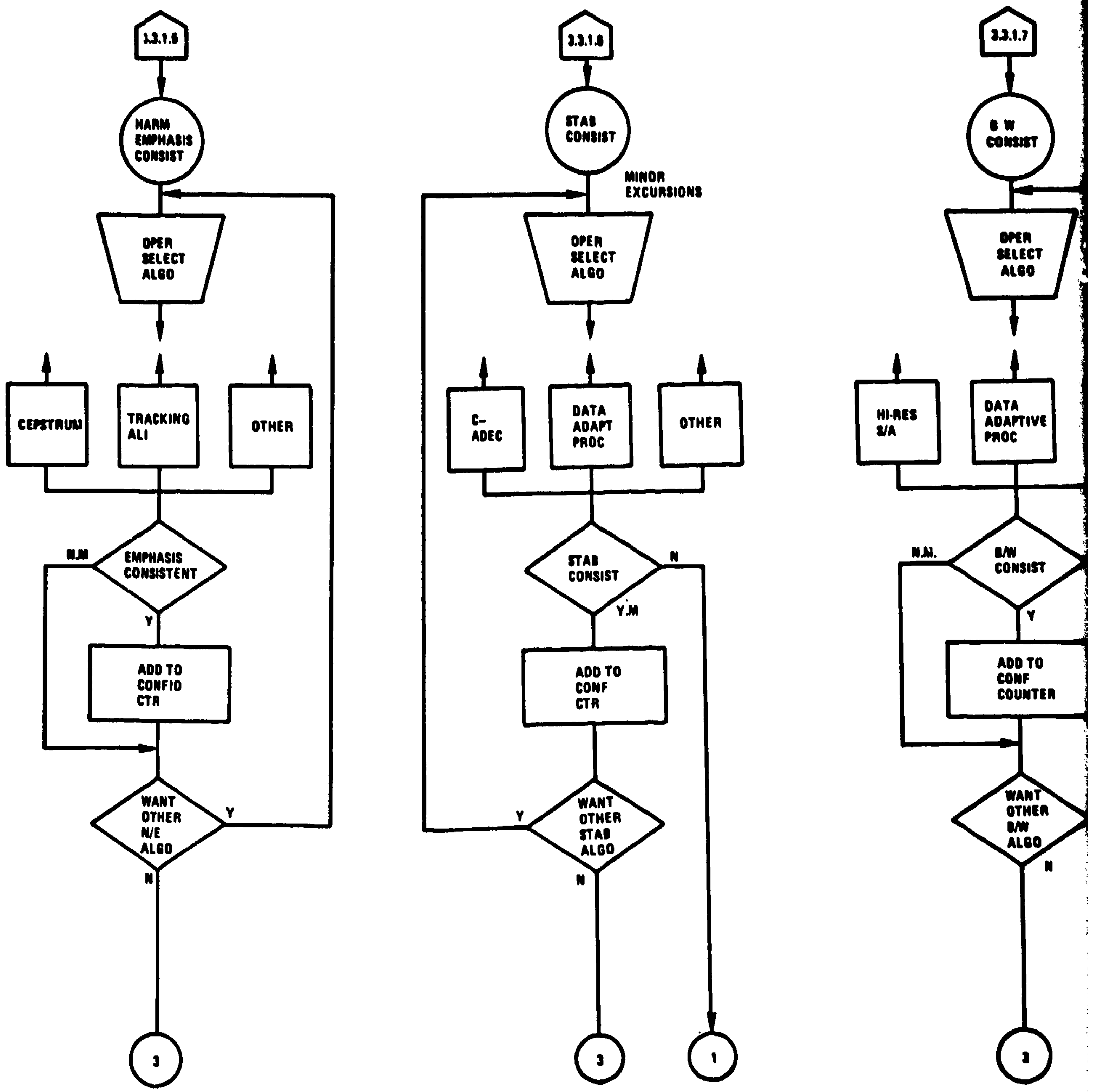
(Pag

2



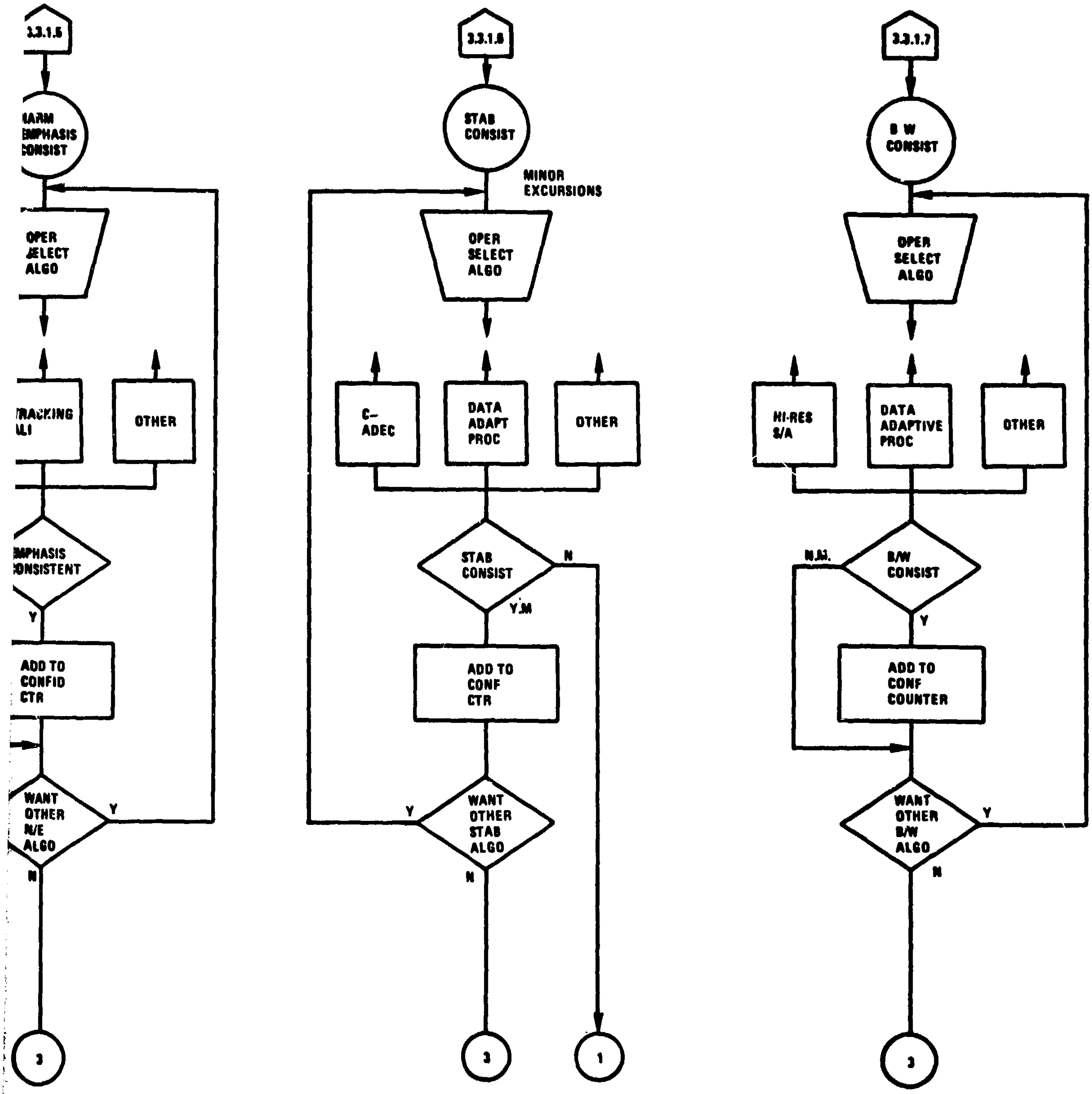
- Harmonic set formation 3rd level diagram (page 2)

3


3.3.1.5
HARM EMPHASIS CONSIST
OPER SELECT ALGO
CEPSTRUM
TRACKING ALI
OTHER
N.M
EMPHASIS CONSISTENT
Y
ADD TO CONFID CTR
WANT OTHER N/E ALGO
Y
N
3
3.3.1.6
STAB CONSIST
MINOR EXCURSIONS
OPER SELECT ALGO
C-ADEC
DATA ADAPT PROC
OTHER
STAB CONSIST
N
Y.M
ADD TO CONF CTR
Y
WANT OTHER STAB ALGO
N
3
1
3.3.1.7
B W CONSIST
OPER SELECT ALGO
HI-RES S/A
DATA ADAPTIVE PROC
N.M.
B/W CONSIST
Y
ADD TO CONF COUNTER
WANT OTHER B/W ALGO
N
3

CO

4



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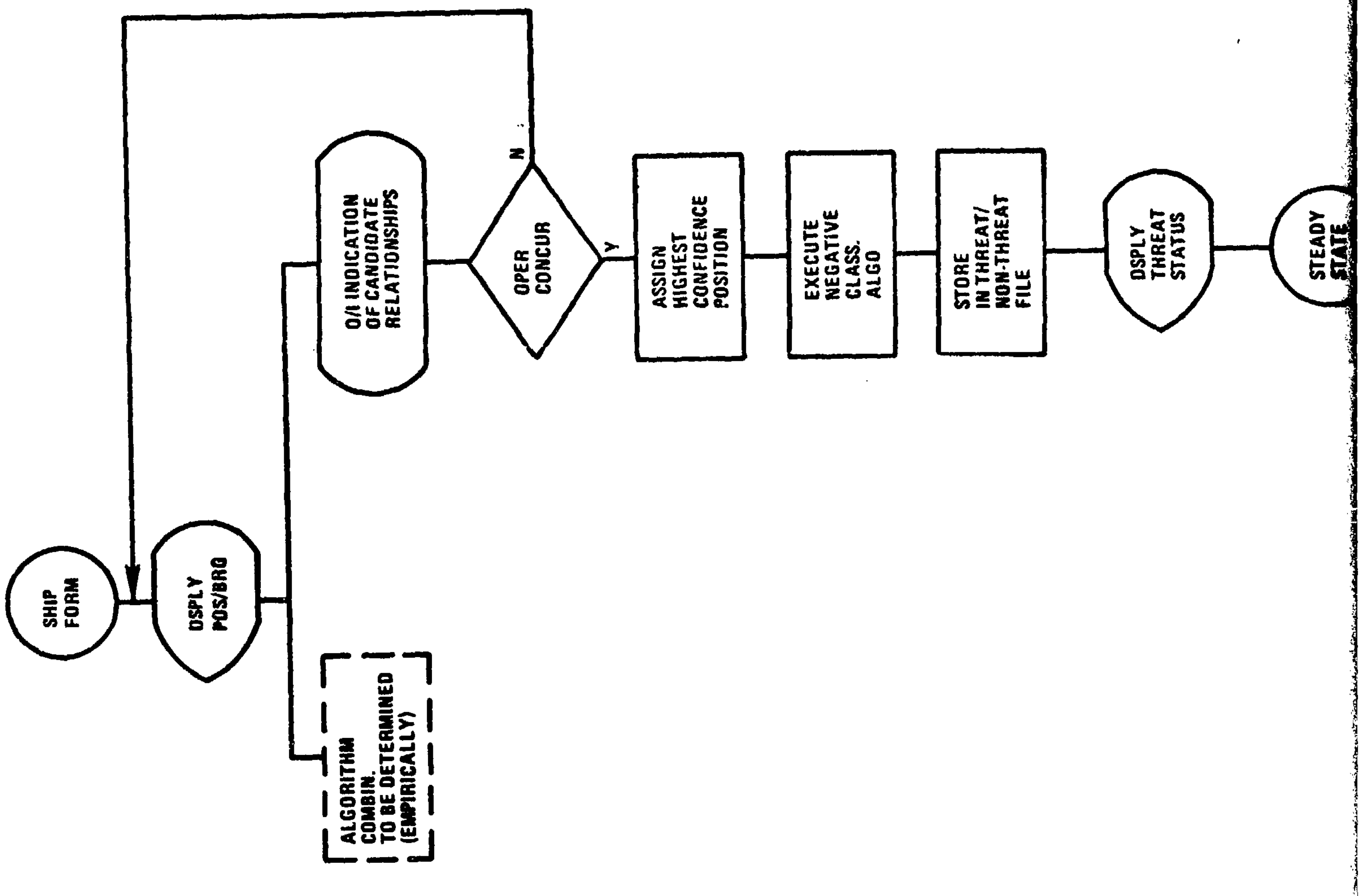
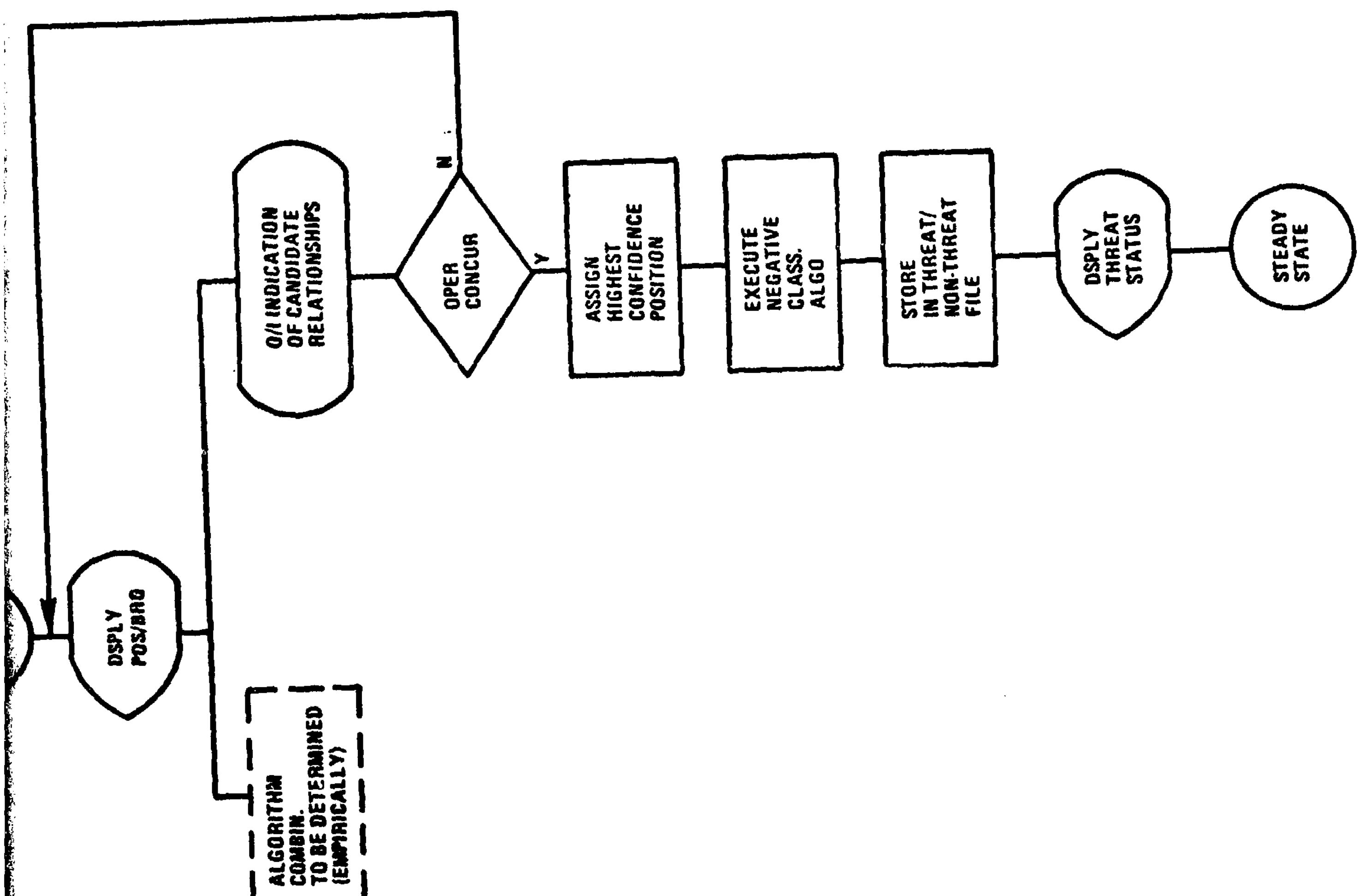
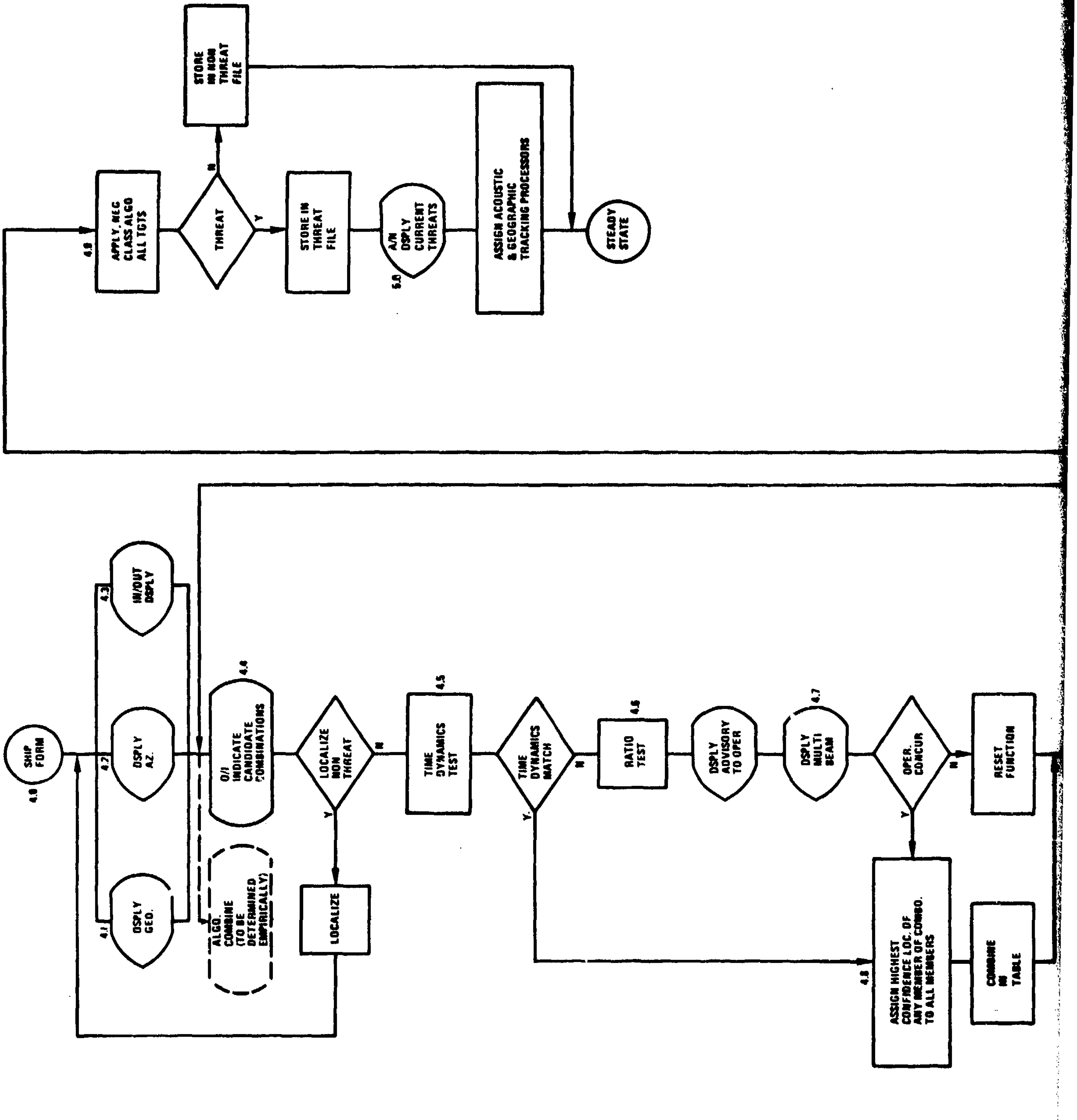
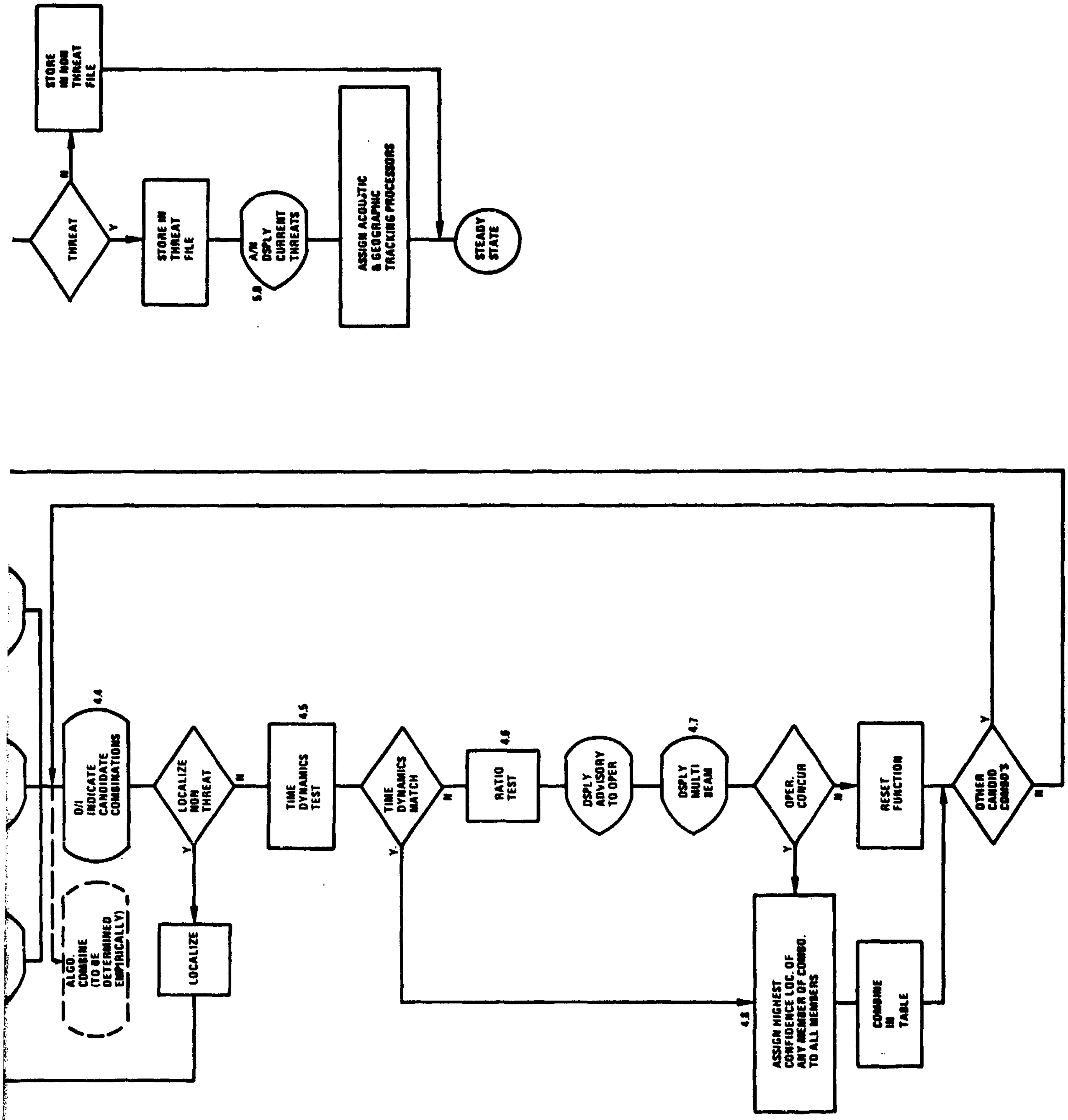

SHIP FORM
DSPLY POS/BRG
ALGORITHM COMBIN. TO BE DETERMINED (EMPIRICALLY)
O/I INDICATION OF CANDIDATE RELATIONSHIPS
OPER CONCUR
N
Y
ASSIGN HIGHEST CONFIDENCE POSITION
EXECUTE NEGATIVE CLASS. ALGO
STORE IN THREAT/ NON-THREAT FILE
DSPLY THREAT STATUS
STEADY STATE



(U) Fig. 6 - Ship signature formation 2nd level diagram

2


STORE IN NON THREAT FILE
4.9
APPLY. NEG CLASS ALGO ALL TGTS
THREAT
N
Y
STORE IN THREAT FILE
A/N DSPLY CURRENT THREATS
5.0
ASSIGN ACOUSTIC & GEOGRAPHIC TRACKING PROCESSORS
STEADY STATE
SHIP FORM
4.0
4.1
DSPLY GEO.
4.2
DSPLY AZ.
4.3
IN/OUT DSPLY
4.4
O/I INDICATE CANDIDATE COMBINATIONS
ALGO. COMBINE (TO BE DETERMINED EMPIRICALLY)
LOCALIZE NON THREAT
LOCALIZE
4.5
TIME DYNAMICS TEST
TIME DYNAMICS MATCH
4.6
RATIO TEST
DSPLY ADVISORY TO OPER
4.7
DSPLY MULTI BEAM
OPER. CONCUR
RESET FUNCTION
4.8
ASSIGN HIGHEST CONFIDENCE LOC. OF ANY MEMBER OF COMBO. TO ALL MEMBERS
COMBINE IN TABLE



(U) Fig. 6A - Ship signature formation 3rd level diagram

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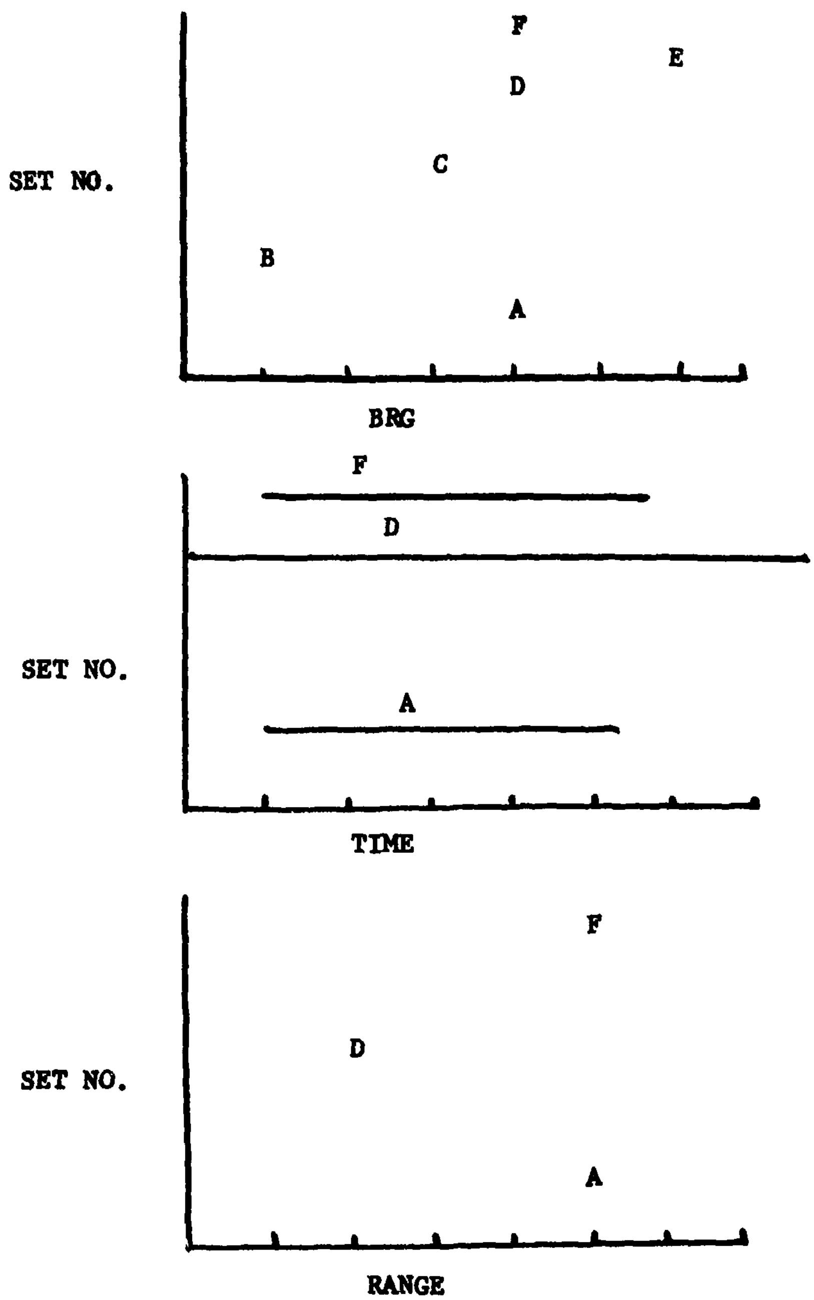
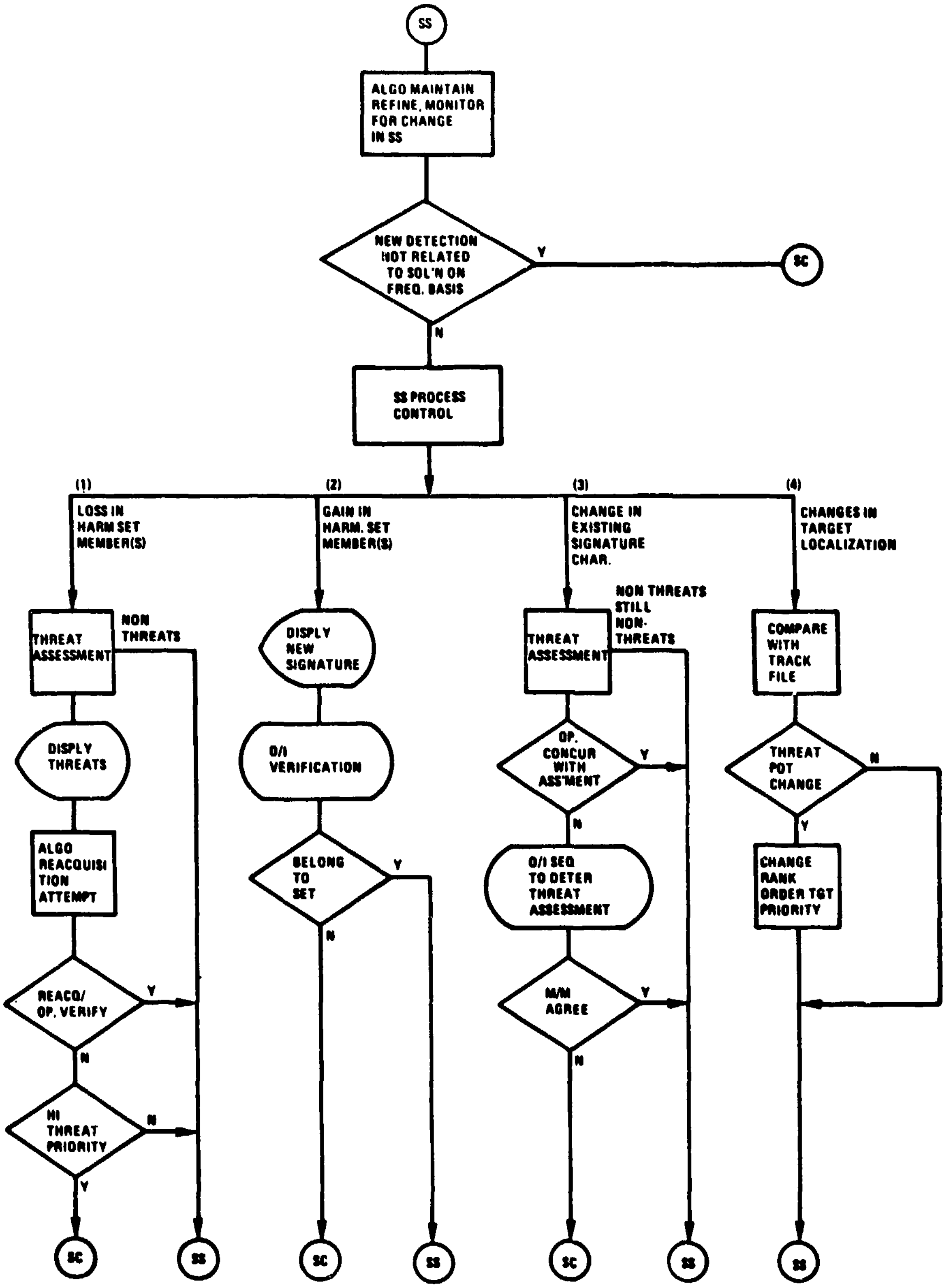
2



(U) Fig. 6B - Display formats



(U) Fig. 7 - Steady state solution 2nd level diagram

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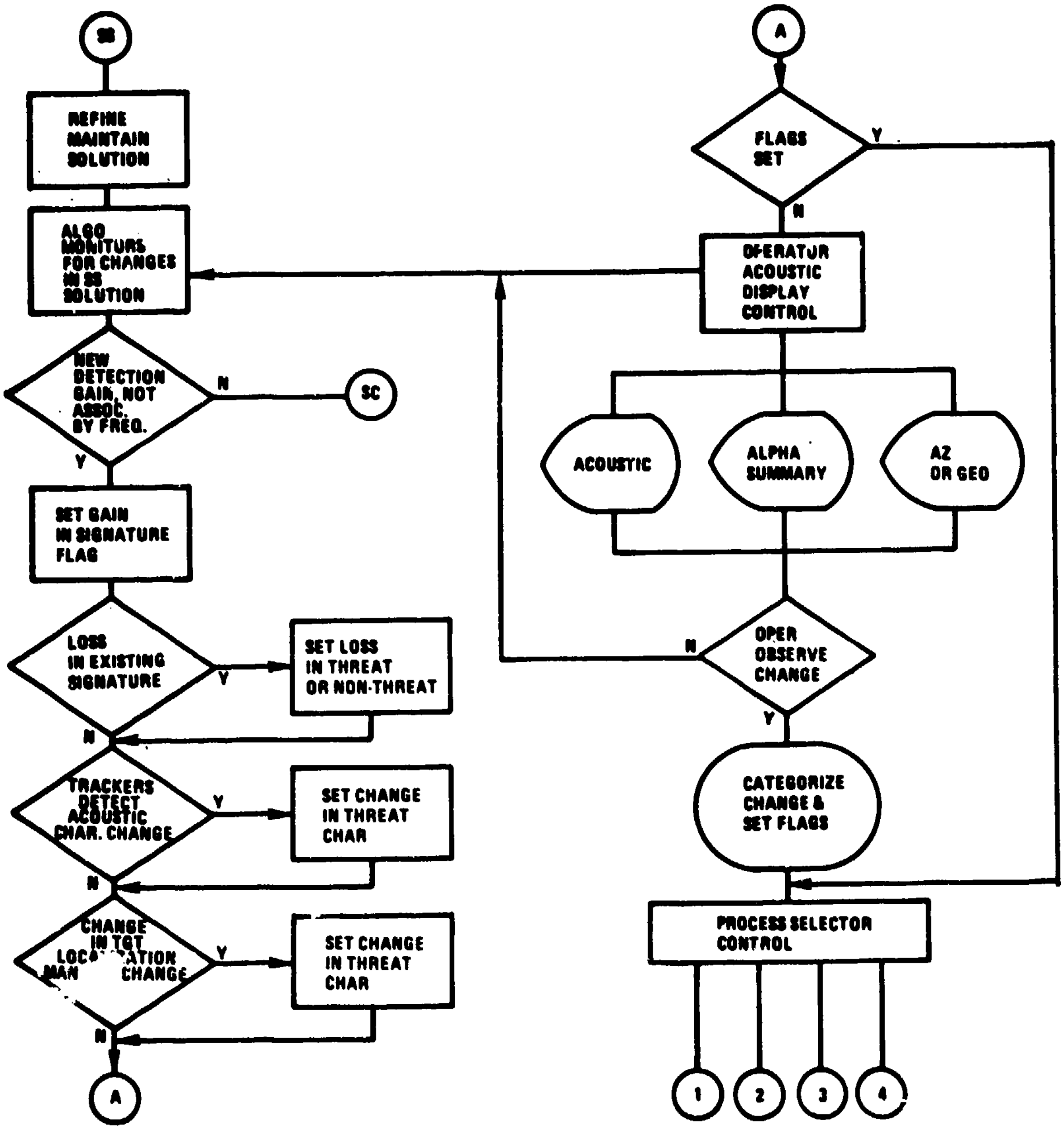
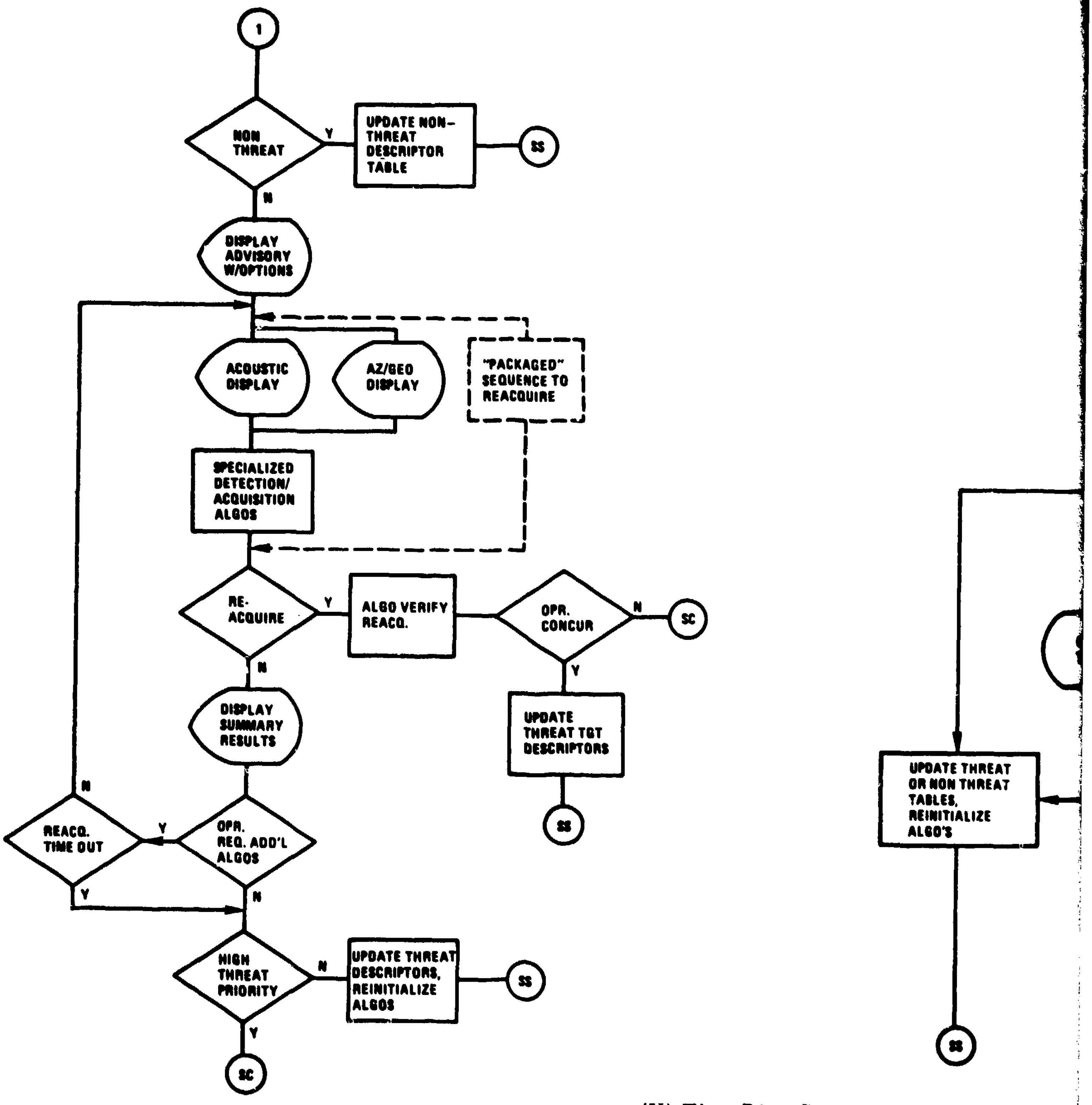


LOSS IN HARMONIC SET MEMBER(S)

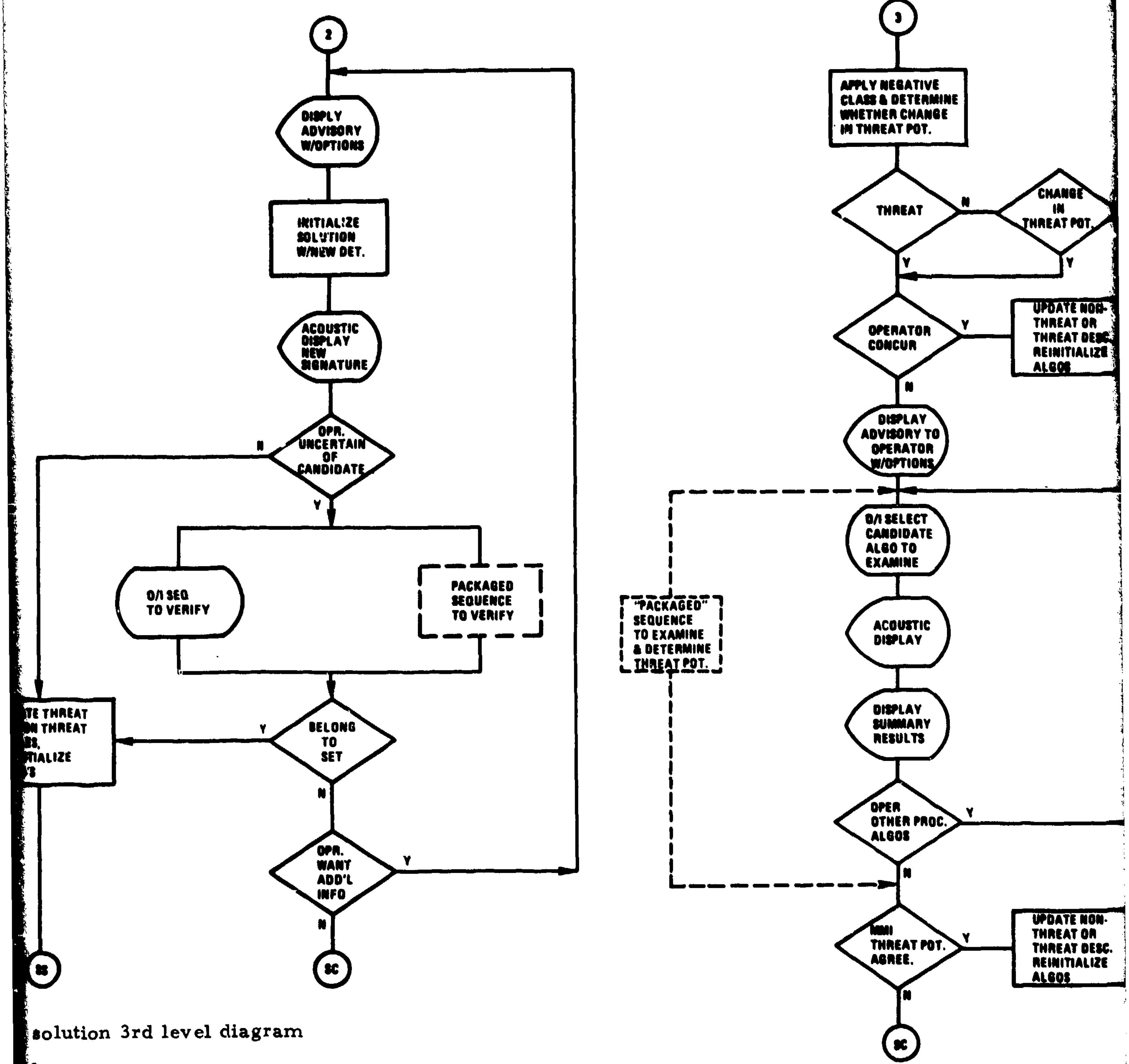


(U) Fig. 7A - Steady state solution 3rd

2

GAIN IN HARM. SET MEMBER(S)

CHANGE IN EXISTING SIGNATURE C

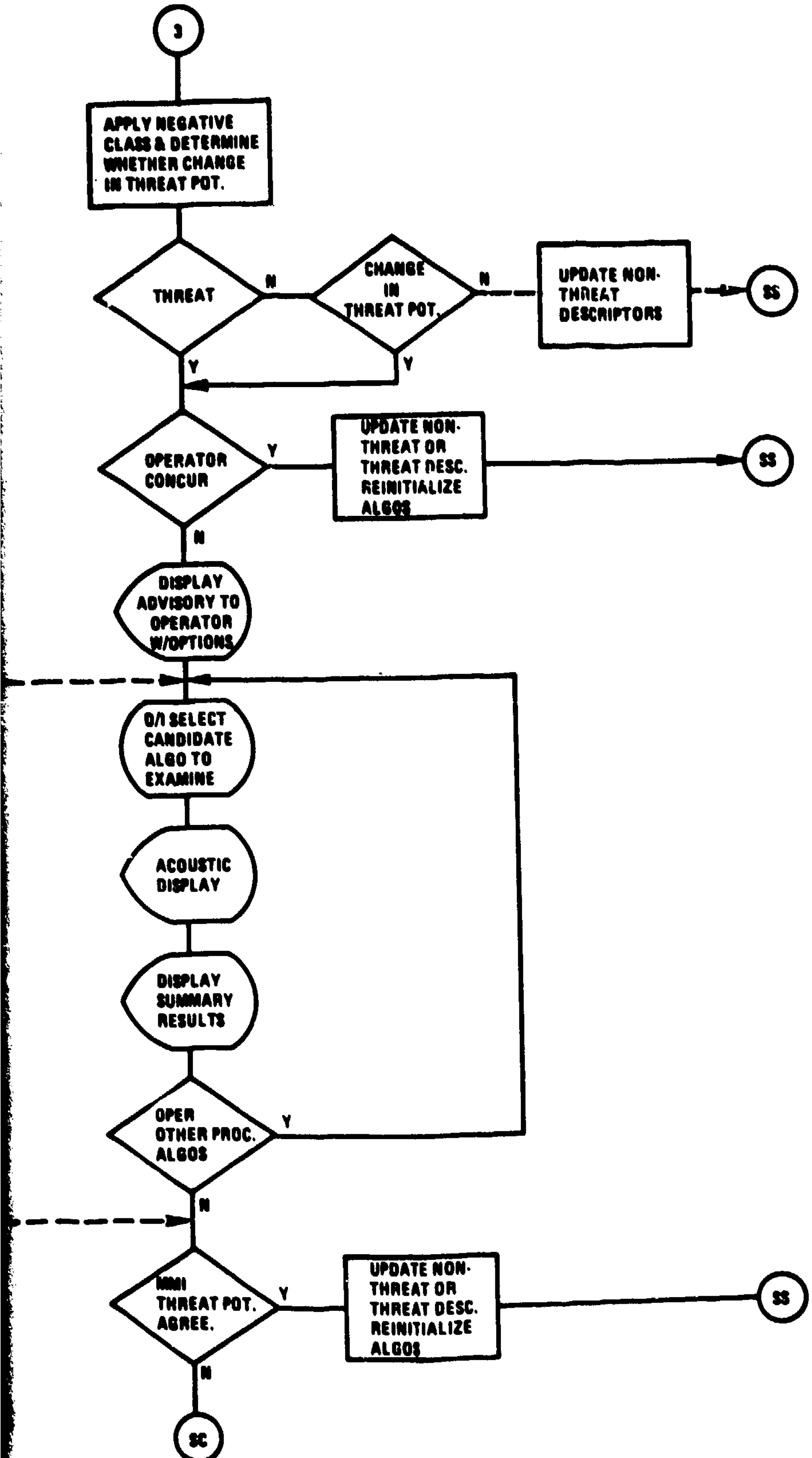


solution 3rd level diagram

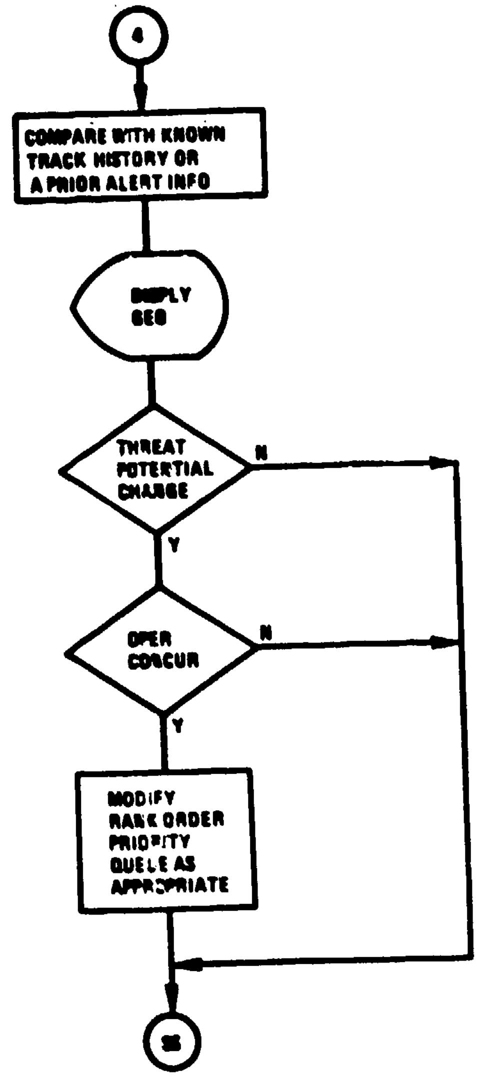
9
) Blank)

3

NGE IN EXISTING SIGNATURE CHARACTERISTICS



CHANGES IN TARGET LOCALIZATION, TRACKING, MANEUVERS



Appendix A

Display System and Interactive Device

Funding constraints made it necessary to plan to conduct the experiment using an on-board display and interactive device.

The display is a DICOMED Corporation Model 36 storage display. The general characteristics are as follows:

a. dark-trace storage type with 10" usable diameter,
b. up to 1600 resolvable points per horizontal trace,
c. 16 displayable intensity levels,
d. full screen image generation in a minimum of 43 seconds, and
e. full screen erase time of 10 seconds.

The interactive device is a Science Accessories Corporation Graf Pen Model GP-2 sonic digitizer. The GP-2 measures the time required for a sound wave to reach each of two orthogonally-mounted linear microphones located on two sides of the DICOMED. The sound source is a spark, generated by closing the gap in the tip of a device resembling a ball point pen by depressing the tip on the face of the screen. Each time the spark jumps the gap, a hypersonic sound wave with a short rise time is generated. The elapsed time between spark generation and reception at each of the two microphones is a unique measure of the position of the pen relative to some fixed reference, for example f_o, t_o on a lofargram, that is, a highly resolved frequency and time coordinate.

The sensor length of the GP-2 is 14 inches, exceeding the usable portion of the DICOMED screen. The resolution over this length is either 2000 or 4000 resolutions depending on whether 11 or 12 bit data words are used, permitting resolution of a displayed lofargram to at least 0.1 hz.

Although the DICOMED-GRAF Pen combination was adequate to permit the experiment to be pursued, there were several shortcomings, principally in the area of support software.

For the DICOMED:

a. No software, at any level, exists to support image generation. Each instruction and data point must be in machine language. All communications protocol between the display and the computer are the programmer's responsibility.

b. Display graphics, including alphanumeric characters, must be written in machine language.

c. No operator interactive hardware or software was available. Common interactive devices like cursors or light pens are not suitable for use with dark trace storage displays.

d. It is the nature of storage displays that modifications to already displayed data are limited. Deletion of previously displayed data requires total erasure of the screen and re-generation of the modified image.

For the GRAF-Pen:

a. A driver to permit GRAF-Pen input-output to the HP-2100A did not exist.

b. The GRAF-Pen was not compatible with the HP-12566B standard interface. (This was resolved by designing and fabricating a second interface between the GRAF-Pen and the computer interface.)

Experimental Display Program:

In order to test the display system, a stand-alone, core resident program was developed to simulate display of real acoustic data. A self-contained subroutine generated pseudo-random background noise for display. Discrete frequency components were entered by the operator on the TTY. Data entry was limited to two multiple-harmonic series, and one unrelated single discrete frequency. Relative amplitude, bandwidth, start and stop times could be specified by the operator.

The image produced was judged of adequate quality and resolution, with the possible exception that the phosphor was of magenta hue, so that amplitude differences were represented visually by shades of purple, rather than gray to black. The problem seems to be in the novelty of the display compared to a paper writer rather than a quantitative difference in visual detection capability.

Display Program:

The following source listing (Fig. 1) permits operator generation of simulated lofar displays and the DICOMED. The program was designed by J. R. Bouffler, Admiralty Research Laboratory, a British exchange scientist working at NRL during part of this development. The display portion of the program is usable in its entirety. The acoustic data input necessarily needs to be rewritten for use with other than simulated data.

```
BILLJ1 T-00003 IS ON CR00002 USING 00024 BLKS R-0000

ASMB,A,L
*
*06JAN76/WJ05
*
*
*DEMONSTRATION PROGRAM
*PARAMETERS ENTERED FROM TTY.
*TWO HARMONIC FAMILIES.
*ALTERNATING LINE.
*STABLE LINE>.
*EDITING.
*
      ORG 2000B
      UNL
STRT  NOP
      CLA
      STA GCNT
      JMP PARD,I
      HLT 60B        WAIT
STA   JSB ERA     GO TO ERASE SUB
      JMP NEXTD,I
STB   JSB OVT
      LDB GCNT
      INB
      STB GCNT
      NOP
      JMP INI
STE   JSB OVT
      CLB
      LDB GCNT
      NOP
      JMP INI2
STD   JSB PNW2,I
      LDA W          FETCH WIGL WORD
      ADA H1T
      STA H1M
      LDA W
      ADA H2T
      STA H2M
      LDA W
      ADA H3T
      STA H3M
      LDA H4T
      ADA W2
      STA H4M
      LDA W3      FETCH WIGL MODR.
      ADA H5T     MOD.LINE
      STA H5M
      LDA W3
      ADA H6T
      STA H6M
      LDA W3
```

Figure 1

```
         ADA H7T
         STA H7M
         LDA AMP4
         SZA              ALT. LINE ?
         JSB ALT            YES-GO TO SUB
         LDA AMP8           NO-
         SZA              SINGLE LINE ?
         JSB SL             YES-GO TO SUB
         JSB KZ             NO-GO TO KNEE ROUTINE
         JSB FS           GO TO FADE IN LINE SUB
NOISE     JSB PNN2,I
         LDB HC             FETCH CELL COUNT
         CPB H1M          IS THERE A FUNDL.LINE?
         JMP *+16
         CPB H2M
         JMP *+16
         CPB H3M
         JMP *+16
         CPB H4M
         JMP *+16
         CPB H5M
         JMP *+16
         CPB H6M
         JMP *+16
         CPB H7M
         JMP *+16
         CPB H8T
         JMP *+16
         JMP THRS
         ADA AMP1         ADD SIGNAL TO NOISE
         JMP *+14
         ADA AMP2
         JMP *+12
         ADA AMP3
         JMP *+10
         ADA AMP4
         JMP *+8
         ADA AMP5M
         JMP *+6
         ADA AMP6M
         JMP *+4
         ADA AMP7M
         JMP *+2
         ADA AMP8M
         RRR 4            BRING 5TH BIT TO END FOR TEST
         SLA              IS AMPLITUDE > MAX?
         JMP *+4
         RRL 4              NO -RETURN TO STATUS QUO
         AND MAX          MASK
         JMP THRS
         LDA MAX          REPLACE S+N EITH MAX.
THRS     LDB THR
         CPB D0           IS THRESHOLDING REQUIRED?
         JMP INT
```

Figure 1 (Continued)

```
        JSB T          YES-GO TO THRESH. ROUTINE
INT     JSB OUT        O/P DOT INTENSITY
        ISZ HC         ? REACHED END OF LINE
        JMP NOISE        NO-GO DO MORE CELLS
        LDA EOLX         YEW-FETCH EOL CODE
        JSB OUT
        LDA HC0        FETCH MAX CELLCOUNT
        STA HC         RESET CELL COUNTER
        ISZ VC1      INCR. LINE COUNTER
        JMP *+2
        JMP FIND,I
        ISZ VC         ? REACHED END OF FRAME
        JMP STD
        LDA GCNT
        SZA
        JMP *+4
        ADA D1
        STA GCNT
        JMP FIND,I
        CLA
        STA GCNT
        JMP FIND,I
        JMP FIND,I
OUT     NOP
        AND MASK
        ADA REQ
        OTA 16B,C
        SFS 16B
        JMP *-1
        CLA
        OTA 16B,C
        JMP OUT,I
*
        SPC 5
*DISPLAY INITIALIZATION ROUTINE
*
ERA     NOP
        CLA
        OTA 16B,C
        STC 16B,C
        LDA IN
        JSB OUT
        LDA ERS        FETCH ERASE CODE
        JSB OUT
        JMP ERA,I
*
INI     NOP
        CLA
        STA CT1
        STA CT2
        STA H1M        SET LINES TO ZERO
        STA H2M
        STA H3M
        STA H4M
```

Figure 1 (Continued)

```
        STA H5M
        STA H6M
        STA H6M
        STA H7M
        STA H8M
        LDA ASD
        STA TEMP1
        LDA AK
        STA TEMP
        LDA DM10
        STA FM
        JSB PNSTD,I
        LDA VC0
        STA VC
        JMP *+2
INI2    NOP
        LDA IN
        JSB OUT
        LDA RPV        FETCH RANDOM POSITION CODE
        JSB OUT
        LDA VCI1
        JSB OUT
        LDA VCI2
        JSB OUT
        LDA RPH        FETCH RANDOM POSITION CODE(HORIZ.)
        JSB OUT
        LDA HCI1
        JSB OUT
        LDA HCI2
        JSB OUT
        LDA VC01
        STA VC1       SET OVERALL COUNTER
        LDA HC0
        STA HC         SET CSLL COUNT
        JMP STD
*
        NOP
*
***CONSTANTS
*
IN      OCT 010000
ERS     OCT 010200
RPV     OCT 010011
RPH     OCT 010010
EOLX    OCT 010002
VCI1    OCT 000304
VCI2    OCT 000002
HCI1    OCT 000373
HCI2    OCT 000000
REQ     OCT 000400
MASK    OCT 070377
*
*KNEE START SUB-ROUTINE
*
```

Figure 1 (Continued)

```
KZ      NOP
        LDA VC
        ADA KST
        SSA
        JMP KZA
        LDA VC
        ADA EK
        SSA
        JMP KZB
        LDA KES
        ADA VC
        SSA
        JMP KZ,I
        LDA KSF
        ADA VC
        SSA
        JMP *+2
        JMP KZA
        LDA TEMP,I
        ADA H1M
        STA H1M
        LDA TEMP,I
        ADA H2M
        STA H2M
        LDA TEMP,I
        ADA H3M
        STA H3M
        LDB TEMP
        ADB DM1
        STB TEMP
        JMP KZ,I
        JMP KZB
        LDA H1T
        STA H1M
        LDA H2T
        STA H2M
        LDA H3T
        STA H3M
        JMP KZ,I
KZA     CLA
        STA H1M
        STA H2M
        STA H3M
        JMP KZ,I
KZB     LDA TEMP,I
        ADA H1M
        STA H1M
        LDA TEMP,I
        ADA H2M
        STA H2M
        LDA TEMP,I
        ADA H3M
        STA H3M
        ISZ TEMP
```

Figure 1 (Continued

```
        JMP *+1
        JMP KZ,I
*
******CONSTANTS
*
TEMP    NOP
AK      DEF K1
K1      DEC -91
K2      DEC -83
K3      DEC -74
K4      DEC -66
K5      DEC -58
K6      DEC -47
K7      DEC -36
K8      DEC -30
K9      DEC -24
K10     DEC -18
K11     DEC -13
K12     DEC -9
K13     DEC -6
K14     DEC -3
K15     DEC -2
K16     DEC -1
K17     DEC 0
K18     DEC 0
K19     DEC 0
*
        SPC 5
*
*ALTERNATOR LINE SUB ROUTINE
*
ALT     NOP
        LDA VC          FETCH LINE COUNT
        ADA AST
        SSA             BEFORE / AFTER LINE START
        JMP ALTA
        LDA VC
        ADA AF
        SSA
        JMP Q
        JMP ALTA
Q       NOP
        LDA TEMP1,I     FETCH MODIFIER
        LDB CT2         FETCH QUADRANT COUNTER
        CPB D0          ? IN QUADRANT 0
        JMP Q0              YES-GO TO QA SECTOR
        CPB D1          ? IN QUADRANT 1
        JMP Q1              YES-GO TO Q1 SECTOR
        CPB D2          ? IN QUADRANT 2
        JMP Q2              YES-GO TO Q2 SECTOR
        CPB D3          ? IN QUADRANT 3
        JMP Q3              YES- GO TO Q3 SECTOR
        HLT 70B             NO1 FAULT CONDITION!
Q0      LDB CT1         FETCH KNEE MODR POINTER
```

Figure 1 (Continued)

```
        CPB D18       REACHED END OF QUADRANT ?
        JSB QC            YES-GO UPDATE QUAD COUNTER
        CMA,INA           NO-MAKE MODR -VE
        ADA H4M
        STA H4M
UP      ISZ CT1       INC MODR POINTER
        JMP *+1
        ISZ TEMP1     INC BUFFER PTR
        JMP ALT,I     EXIT
QC      NOP
        ISZ CT2       INCREMENT QUAD CTR
        JMP QC,I
        JMP QC,I      RETURN
Q1      LDB CT1       FETCH MODR COUNTER
        CPB D0        REACHED END OF QUADRANT ?
        JSB QC            YES-GOINC QUAD COUNTER
        CMA,INA           NO-MAKE MODR -VE
        ADA H4M
        STA H4M
DOWN    LDB CT1
        ADB DM1       DECREMENT COUNTER
        STB CT1
        LDA TEMP1     FETSH MODR BUFFER PTR
        ADA DM1       DECREMENT
        STA TEMP1
        JMP ALT,I
Q2      LDB CT1       FETCHNMODR COUNTER
        CPB D18       REACHED END OF QUADRANT
        JSB QC            YES GO INC QUAD COUNTER
        ADA H4M
        STA H4M
        JMP UP        GO INC MODR CTR & PTR
Q3      LDB CT1       FETCH MODR CTR
        CPB D0        REACHED END OF QUADRANT ?
        JMP *+4
        ADA H4M
        STA H4M
        JMP DOWN      GO DECREMENT MODR CTR & PTR
        CLA           GET ZERO & LOAD INTO-
        STA CT2        QUAD CTR TO RESET
        JMP *-5
ALTA    CLA
        STA H4M
        JMP ALT,I
*
*****CONSTANTS
*
TEMP1   NOP
        NOP
        NOP
        NOP
CT1     NOP
CT2     NOP
ASD     DEF L0
```

Figure 1 (Continued)

```
L0     DEC 0
L1     DEC 1
L2     DEC 2
L3     DEC 3
L4     DEC 3
L5     DEC 4
L6     DEC 5
L7     DEC 6
L8     DEC 6
L9     DEC 7
L10    DEC 7
L11    DEC 8
L12    DEC 8
L13    DEC 9
L14    DEC 9
L15    DEC 10
L16    DEC 10
L17    DEC 10
L18    DEC 10
L19    DEC 10
*
       SPC 5
*
*FAMILY 2:FADE IN/OUT
*
FS     NOP
       LDA VC
       ADA FST
       SSA            +/-:BEFORE/AFTER FADE START?
       JMP FSA         -VE:BEFORE
       LDA VC
       ADA FSE
       SSA            +/-:IN/BEYOND ZONE OF FADE START
       JMP FSB         -VE:IN ZONE
       LDA VC          +VE:BEYOND (NORMAL)
       ADA FO
       SSA            +/-:BEFORE/AFTER FADE OUT ZONE?
       JMP FS,I        -VE:BEFORE (NORMAL)
       LDA VC          +VE:AFTER FADE OUT ZONE
       ADA FE
       SSA            +/-:IN/BEYOND FADE OUT ZONE?
       JMP FSC         -VE:IN ZONE
       SPC 1
FSA    CLA             +VE:BEYOND:NO LINE
       STA H5M
       STA H6M
       STA H7M
       JMP FS,I
       SPC 1
FSB    JSB FMOD
       ISZ FM         INCREMENT POINTER
       JMP FS,I       EXIT
       JMP FS,I       EXIT
FSC    JSB FMOD       GO-MODIFY AMPLITUDE
```

Figure 1 (Continued)

```
        LDB FM
        ADA DM1         DECREMENT MODIFIER
        STB FM
        JMP FS,I
        SPC 1
FMOD    NOP
        LDA FM          FETCH FADE MODIFIER
        ADA AMP5        MOD. AMPLITUDE OF LINE
        SSA,RSS         IS IT -VE?
        JMP *+2           NO: +VE: HOLD
        CLA               YES:-VE: SET AMPLITUDE
        STA AMP5M
        LDA FM
        ADA AMP6
        SSA,RSS
        JMP *+2
        CLA
        STA AMP6M
        LDA FM
        ADA AMP7
        SSA,RSS
        JMP *+2
        CLA
        STA AMP7M
        JMP FMOD,I
        SPC 5
*
*SINGLE LINE
*
SL      NOP
        LDA VC
        ADA SS
        SSA             BEFORE/AFTER START OF LINE?
        JMP *+5          -VE:BEFORE (NO LINE)
        LDA VC           +VE:AFTER
        ADA SF
        SSA             IN/BEYOND LINE ZONE?
        JMP *+4
        CLB              +VE:BEYOND:NO LINE
        STB AMP8M       SET AMPL. TO ZERO
        JMP SL,I        EXIT
        LDB AMP8
        STB AMP8M       SET AMPL, TO NORMAL
        JMP SL,I
        SPC 5
*
*THRESHOLD SUB-ROUTINE
*
**SET THRESHOLD LEVEL BITS 0-3,IN SWITCH REGISTER
**TO CHANGE DURING 'GRAM GENERATION,
**MAKE SW. REG. BIT 15 = '1'
*
T       NOP
        CMB,INB         MAKE -VE
```

Figure 1 (Continued)

```
       ADB 0000       ADD TO POINT LEVEL
       SSB            -VE ? (ABOVE/BELOW THRESH. LEVEL ?)
       JMP *+3          BELOW
       LDA MAX          ABOVE - FETCH MAX INTENSITY
       JMP T,I        EXIT
       LDA MIN        FETCH MIN INTENSITY
       JMP T,I
*
MIN    OCT 000000
       SPC 5
*
*FREQUENCY & TIME MARKS
*
OVT    NOP
       CLA
       OTA 16B,C
       STC 16B
       LDA IN
       JSB OUT
       LDA RPV
       JSB OUT
       LDA VCI1
       ADA DM35
       JSB OUT
       LDA VCI2
       JSB OUT
       LDA RPH
       JSB OUT
       LDA HCI1
       ADA DM66
       JSB OUT
       LDA HCI2
       JSB OUT
       LDA DM35
       STA VC1
FC     LDA HC0
       ADA DM66
       STA HC
       LDA HC0
       STA HCC
FCF    LDB HC
       CPB HCC
       JMP *+4
       LDA MIN
       JSB OUT
       JMP *+6
       LDA MAX
       JSB OUT
       LDA HCC
       ADA D100
       STA HCC
       ISZ HC
       JMP FCF
       LDA EOLX
```

Figure 1 (Continued)

```
      JSB OUT
      ISZ VC1
      JMP FC
      LDA DM66
      STA HC
      LDA VC01
      STA VCC
      LDA VC01
      STA VC1
TCF   LDA VC1
      CPA VCC
      JMP *+10
      LDA MIN
      JSB OUT
      LDA EOLX
      JSB OUT
      LDA DM66
      STA HC
      ISZ VC1
      JMP TCF
      JMP OVT,I
TC    LDA MAX
      JSB OUT
      ISZ HC
      JMP TC
      LDA EOLX
      JSB OUT
      LDA DM66
      STA HC
      LDA VCC
      ADA D120
      STA VCC
      ISZ VC1
      JMP TCF
      JMP OVT,I
*
*CONSTANTS
*
DM35  DEC -35
DM66  DEC -66
D120  DEC 120
HCC   NOP
*
      SPC 5
*
*BANDWIDTH SUB-ROUTINE
      ORG 12000B
      NOP
PNW   NOP
      CLB
      LDA GEN3
      SLA
      INB
      ARS,ARS
```

Figure 1 (Continued)

```
      SLA
      INB
      ARS
      SLA
      INB
      ARS,ARS
      SLA
      INB
      SLB
      JMP *+3
      CLE
      JMP *+2
      CCE
      LDA GEN3
      ERA
      STA GEN3
      LDB MSKB
      CPB D3
      JMP *+4
      CPB D7
      JMP *+4
      ADA DM1
      JMP *+2
      ADA DM3
      AND MSKB
      STA W
      LDA GEN3
      AND MAX
      STA W2
      LDA GEN3
      RRR 4
      AND MSKC
      LDB MSKC
      CPB D3
      JMP *+4
      CPB D7
      JMP *+4
      JMP *+4
      ADA DM1
      JMP *+2
      ADA DM3
      STA W3
      JMP PNW,I
*
****CONSTANTS
*
      SPC 5
*
*
*10JAN74/JB/19
*
*PN20M = PN20 GENERATOR MODIFIED TO AN
*APPROXIMATE NORMAL DISTRIBUTION
*
```

Figure 1 (Continued)

```
PNST  NOP
      CCA
      STA GEN1      SET
      STA GEN2       PN
      STA GEN3        REGISTERS
      CLA
      STA CT15      CLEAR
      STA CT14       PN
      STA CT13        COUNTERS
      STA CT12
      STA CT11
      STA CN10
      STA CT9
      STA CT8
      JMP PNST,I
PNN   NOP
      CLB
      LDA GEN2
      RRR 3
      XOR GEN2
      SLA
      JMP *+3
      CLE
      JMP *+2
      CCE
      LDA GEN2
      LDB GEN1
      ELB,ELB
      ELB,ELB
      ERA
      STA GEN2
      ERB,ERB
      ERB,ERB
      ERB
      STB GEN1
      LDA GEN2
      AND MAX        MASK OUT ALL BUT REQD. BITS
      CPA A15
      JMP *+16           YES - GO SEE IF MODIFICATION REQD.
      CPA A14
      JMP *+24                  YES
      CPA A13
      JMP *+32
      CPA A12
      JMP *+40
      CPA A11
      JMP *+48
      CPA A10
      JMP *+56
      CPA A9
      JMP *+64
      CPA A8
      JMP *+72           YES - GO SEE IF MODN. REQD.
      JMP PNN.I          NO - EXIT
```

Figure 1 (Continued)

```
LDB CT15        FETCH "15" COUNTER
CPB D80         IS THE ONE TO BE O/P?
JMP *+5           YES - GO DO IT
INB             UPDATE "15" COUNTER
STB CT15
LDA A0
JMP PNN,I       EXIT
CLB
STB CT15
JMP PNN,I
LDB CT14
CPB D40
JMP *+5
INB
STB CT14
LDA A1
JMP PNN,I
CLB
STB CT14
JMP PNN,I
LDB CT13
CPB A16
JMP *+5
INB
STB CT13
LDA A2
JMP PNN,I
CLB
STB CT13
JMP PNN,I
LDB CT12
CPB A8
JMP *+5
INB
STB CT12
LDA A3
JMP PNN,I
CLB
STB CT12
JMP PNN,I
LDB CT11
CPB A4
JMP *+5
INB
STB CT11
LDA A4
JMP PNN,I
CLB
STB CT11
JMP PNN,I
LDB CN10
CPB A2
JMP *+5
INB
```

Figure 1 (Continued)

```
        STB CN10
        LDA A5
        JMP PNN,I
        CLB
        STB CN10
        JMP PNN,I
        LDB CT9
        CPB A3
        JMP *+4
        INB
        STB CT9
        JMP PNN,I
        CLB
        STB CT9
        LDA A6
        JMP PNN,I
        LDB CT8
        CPB A5
        JMP *+4
        INB
        STB CT8
        JMP PNN,I
        CLB
        STB CT8
        LDA A7
        JMP PNN,I
*
****CONSTANTS ETC.
*
A0      DEC 0
A1      DEC 1
A2      DEC 2
A3      DEC 3
A4      DEC 4
A5      DEC 5
A6      DEC 6
A7      DEC 7
A8      DEC 8
A9      DEC 9
A10     DEC 10
A11     DEC 11
A12     DEC 12
A13     DEC 13
A14     DEC 14
A15     DEC 15
A16     DEC 16
GEN1    NOP
GEN2    NOP
CT15    NOP
CT14    NOP
CT13    NOP
CT12    NOP
CT11    NOP
CN10    NOP
```

Figure 1 (Continued)

```
CT9    NOP
CT9    NOP
D40    DEC 40
D80    DEC 80
*
       SKP
*
*LINE INTEGRATION ROUTINE
*
       ORG 3100B
ED2    NOP
       LDA HCO
       STA F/HC
       LDA EF
       STA EF1
       CLB
       DIV D3
       STA EF1/3
       CLB
       MPY D2          FIND 2ND SUB-HARMONIC
       STA EF2/3
       LDA EF
       CLB
       DIV D2          FIND 1ST SUB HARMONIC
       STA EF1/2
       CLB
       MPY D3          FIND HARMONIC
       STA EF3/2
       LDA EF
       CLB
       MPY D2
       STA EF2
       LDA EF
       CLB
       MPY D3
       STA EF3
       SPC 1
       LDB S1D
       STB S1T
       LDB S2D
       STB S2T
       LDB S3D
       STB S3T
       LDB S4D
       STB S4T
       LDB S5D
       STB S5T
       LDB S6D
       STB S6T
       LDB S7D
       STB S7T
       SPC 1
       LDA FL
       INA
```

Figure 1 (Continued)

```
      CMA,INA
      STA CNT      SET COUNTER
CLR   CLA
      STA S1T,I
      STA S2T,I
      STA S3T,I
      STA S4T,I
      STA S5T,I
      STA S6T,I
      STA S7T,I
      ISZ S1T
      ISZ S2T
      ISZ S3T
      ISZ S4T
      ISZ S5T
      ISZ S6T
      ISZ S7T
      ISZ CNT      INCREMENT CTR.
      JMP CLR      RETURN & CLEAR REMAINDER
      JSB PNSTD,I
      SPC 1
STRT3 LDA VCL
      ADA VC0      CONVERT TO LINE COUNT
      STA VCL2     =END OF INTEGRATION BLOCK
      LDA TL       FETCH BLOCK LENGTH
      CMA,INA
      ADA VCL2
      STA VCL1     =START OF INTEGRATION BLOCK
      CLB
      LDA FL       FETCH BLOCK WIDTH
      DIV D2
      CMA,INA
      STA FL/2     HALF BLOCK WIDTH(-VE)
      LDA F/HC
      ADA FL/2
      STA FCON
      LDA EF1/3    FETCH 1/3RD HARM.
      ADA FCON     CONVERT TO CELL NUMBER
      STA HL1
      LDA EF1/2    FETCH 1/2 HARM.
      ADA FCON
      STA HL2
      LDA EF2/3
      ADA FCON
      STA HL3
      LDA EF
      ADA FCON
      STA HL4
      LDA EF3/2
      ADA FCON
      STA HL5
      LDA EF2
      ADA FCON
      STA HL6
```

Figure 1 (Continued

```
         LDA EF3
         ADA FCON
         STA HL7
         LDB HC0
         STB HC
         LDB VC0
         STB VC         SET LINE COUNTER
         NOP
         NOP
CV       LDA VC
         CMA,INA
         ADA VCL1       VCL1-VC
         SSA,RSS        VCL1>VC ?
         JMP NO1          +VE:YES:BEFORE STARRT OF BLOCK
         LDA VC           -VE:NO:AFTER STRT OF BLOCK
         CMA,INA
         ADA VCL2       VCL2-VC
         SSA            VCL2>VC ?
         JMP AVD,I
         SPC 1
         LDA EF1/3
         ADA DM120
         SSA             IS EF1/3 < 12HZ ?
         JMP *+2           YES - TRY NEXT
         JMP CS1A          NO - GO TO SEARCH SUB
         LDA EF1/2
         ADA DM120
         SSA             IS EF1/2 < 12HZ ?
         JMP *+2
         JMP CS2A
         LDA EF2/3
         ADA DM120
         SSA
         JMP CS4A         YES-GO TO ED.FREQ.SEARCH
         JMP CS3A         NO - @GO TO SEARCH SUB
         NOP
         SPC 1
CS1A     LDB S1D
         STB S1T
         LDB FL
         INB
         CMB,INB
         STB CNT
CS1      LDB HC         FETCH CELL COUNT
         CMB,INB        MAKE -VE
         ADB HL1        ADD TO FIRST LINE POSITION
         SSB,RSS        REACHED THIS POSITION YET ?
         JMP *+2          NO:BEFORE START
         JMP *+3          YES:INTO BLOCK
         JSB NO4        GO TO NOISE ONLY ROUTINE
         JMP CS1        RETURN FOR FURTHER TEST
         JSB NO2        GO TO INTEGRATING ROUTINE
         SPC 1
CS2A     LDB S2D
```

Figure 1 (Continued)

```
        STB S1T       SET BUFFER POINTER
        LDB FL        FETCH BLK WIDTH
        INB
        CMB,INB       MAKE -VE
        STB CNT       SET COUNTER
CS2     LDB HC
        CMB,INB
        ADB HL2
        SSB,RSS
        JMP *+2
        JMP *+3
        JSB N04
        JMP CS2
        JSB N02
        SPC 1
CS3A    LDB S3D
        STB S1T
        LDB FL
        INB
        CMB,INB
        STB CNT
CS3     LDB HC
        CMB,INB
        ADB HL3
        SSB,RSS
        JMP *+2
        JMP *+3
        JSB N04
        JMP CS3
        JSB N02
```

Figure 1 (Continued)

Appendix B

Display System Selection (U)

Reference: (a) "State-of-the-Art Summary - Candidate Display Systems for the Integrated Undersea Surveillance System" (U) (NRL Background Document Prepared for PME-124, June 1976)(S).

(b) Display Subsystem Recommendations for the Operator/ Machine Interaction Program (U) - NRL Report dtd 1 Dec 1976 (S).

I. Background

Although display system selection was determined ultimately by funding constraints, a considerable effort in comparative evaluation and selection of displays was expended and reported on in references (a) and (b). Reference (a) is a comprehensive study of several different display requirements, including large screen tactical displays. Reference (b) focuses on specific requirements for the operator-interactive signature formation effort.

This appendix summarizes the findings and recommendations under reference (b) only. For a detailed understanding of the selection process, refer to references (a) and (b).

II. Overview of Requirements

The general requirements for any candidate display system were:

- Flexibility

  .Must be capable of displaying:

  a. lofargrams with varying bandwidths and resolutions
  b. automatic line integrations
  c. A scan
  d. stacked A scan
  e. ambiguity functions

- Long Term Viewing Suitability

  Factors contributing to operator misinterpretation or fatigue such as flicker, noise, low brightness or contrast, focusing inaccuracies must be minimal.

- Adequate Resolution/Data Density

Within the limits of human visual acuity, the number of displayable points was to match the frequency resolution of the FFT. A range of between 1000 and 3000 points on both x and y axes was considered. A minimum of 8 levels of intensity were required for any point written.

- Interactive Capability

Any one of a number of interactive devices (e.g., light/sonic pens, potentiometer devices, function keys, etc.) were basically acceptable. The major requirement was that the interactive system be simple in operation and not require extensive manual entry by the operator.

- Self Contained

A complete graphics display system was required, one which could be interfaced directly to the NRL computer. Development of a display subsystem, per se, was never contemplated. Image refresh, interactive peripheral interface, character and vector generation were to be features of the display controller.

- Mature Technology

The display system had to be commercially available with no system hardware or software development required.

III. Specific Display Characteristics

- Raster Scan CRT
- Minimum 512 x 512 resolvable elements
- Monochrome with gray scale
- Local refresh with computer interface
- Local intelligence
- Keyboard, function keys, joystick or trackball
- Minimum 9" horizontal viewing axis

- Raster Scan CRT

Raster scan was determined to be more suitable for the type of high-data density display (principally lofargrams) required. The constant storage requirement of a raster scan system was expected to simplify display programming significantly.

- Minimum 512 x 512 Resolvable Elements

  Although our preference was to match display resolution to analyzer resolution (i.e., about 1500 points in the horizontal direction for lofar displays), the cost constraints on the program forced us to accept a loss in minimum detectable signal of .5 to 1 dB for each halving of resolution.

- Monochrome With Gray Scale

  Color as a means of encoding signal amplitude was rejected because of the limited range available before psycho-p ysical problems in recognition are encountered. Amplitude variations with time could be most confusing to an operator. (A detailed study of the relative merits of color vs gray scale was beyond the scope of this study. (References (a) and (b) give considerably more detail and cite other studies). The range of quantizations considered was from six bits (64 levels) to three bits (8 levels). Since work done by several large corporations revealed that there is no significant loss in weak signal detection when quantization is reduced to three bits (8 levels) for a time-frequency display, this bit format was accepted. It may be possible to reduce bit requirements further.

- Local Refresh With Computer Interface

  The size of the host computer, (HP-2100A, 32K words) necessitates a large refresh memory associated with the display itself. Computer interface must be of the full-duplex 16-bit parallel register design so as to be compatible with H/P or DEC manufactured computers.

- Local Intelligence Requirements

  - Display related operations can be accomplished at a level above machine language
  - End point vector and conic generator for simple graphics specification
  - A hardware character generator with a minimum of 64 ASCII characters
  - Scaling ability
  - Hardware scrolling
  - Status and control information for peripherals
  - Selective erase
  - Ability to recognize interactive inputs
  - Independent image overlay

- Keyboard, Function Keys, Joystick

  The requirement is that the interaction of the operator with the display must be both simple and minimal. The keyboard must also function in a local mode, not requiring intervention of the host computer.

- Minimum 9" Horizontal Viewing Axis

  This allows lofargrams to be displayed without frequency axis compression.

III. Comparison of Candidate Displays

A comparison of four candidate displays is given in Table 3-1. Detailed comparison is made in reference (b).

IV. Implementation Candidate

The system best meeting the technical and cost requirements was the RAMTEK 9300 Graphic Display System. A detailed description of the RAMTEK 9300 is given in reference (b).

Table 3-

SYSTEM	CA								
	512 x 512 Resolvable Elements	≤ Gray Lead	Color Available	Local Refresh w/ PDP-11 I/F	LOCAL INTELLIGENCE				
					Vector Conics	Char Gen.	Instr. Set	Hardware Scaling	Hard Scro
Comtal 30SA	X	X	X	X(1)					
Comtal 65SA	X	X		X(1)					
Aydin 5214A	X	X	X	X	X	X	X	(2)	
Ramtek 9300	X	X	X	X	X	X	X	X	

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Table 3-I. Comparison of Candidate Display Systems

CATEGORIES								
ELLIGENCE							Keyboard	Min. 9" H Viewing A
dware ling	Hardware Scrolling	Selective Erase	Access re-fresh memory	Separate over-lay channels	Logical/Arith. functions	Gray level windowing		
		X	X	X		X		X
		X	X	X		X		X
(2)	X	X	X		X(3)	X	X	X
X	X	X	X	X	X	X	X	X

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Systems

e over- nnels	Logical/Arith. functions	Gray level windowing	Keyboard	Min. 9" Horiz. Viewing Axis	Est. Cost K$ (4)	Notes
		X		X	26	(1) Would need separate interface for keyboard since not available by manufacturer.
		X		X	51	(2) By software
	X(3)	X	X	X	45	(3) Limited to or-ing or erase ones.
	X	X	X	X	37	(4) Estimated cost for system configured with available options and computer interface needed. Computer costs are not included (see text).

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UNITED STATES GOVERNMENT
Memorandum

7100-032

DATE: 26 February 2004

REPLY TO ATTN OF: Burton G. Hurdle (Code 7103)

SUBJECT: REVIEW OF REF (A) FOR DECLASSIFICATION

TO: Code 1221.1

REF: (a) "Operator-Interactive Signature Formation for Acoustic Undersea Surveillance Systems" (U), William P. Morrogh, Acoustics Division, NRL Memo Report 3625, October 1977 (C)

1. Reference (a) describes an exploratory development to systematically organize signals received on Undersea Surveillance Systems (including several reception locations) to identify the signatures of ships and other sources. The method has not been completed or tested.

2. The technology and equipment of reference (a) have long been superseded. The current value of these papers is historical

3. Based on the above, it is recommended that reference (a) be declassified and released with no restrictions

Burton G. Hurdle
BURTON G. HURDLE
NRL Code 7103

CONCUR:

Edward R. Franchi 3/1/2004
E.R. Franchi Date
Superintendent, Acoustics Division

CONCUR:

Tina Smallwood 3/3/04
Tina Smallwood Date
NRL Code 1221.1